University of Alberta

Integrated 3D-CAD Information System for Estimation in Industrial Construction Projects

By

Rajesh Kandanala

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

In

Construction Engineering and Management

Department of Civil and Environmental Engineering

Edmonton, Alberta

Spring 2005

0-494-08093-0

Library and Archives Canada

Published Heritage Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et Archives Canada

Direction du Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file *Votre référence*
ISBN:
Our file *Notre référence*
ISBN:

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

ABSTRACT

Information management is critical to the success of any construction project. Discipline-specific models contribute to misinterpretation of information and increasingly result in construction site errors and rework. The primary objective of this research is to integrate 3D-CAD model with the information management system (IMS) to enable automated quantity take-off from the 3D-CAD model and share project information from various disciplines. The proposed methodology has been incorporated into a computer system that integrates IMS with 3D-CAD model through a central database. The storage of project data in a central database allows all the project participants to access historic and current data in a central location, ensuring consistency, integrity, and accuracy. This research complements the previous effort by the construction engineering and management group at University of Alberta in collaboration with an industrial partner from Edmonton, Canada. A case study is presented to illustrate the essential features of the developed system.

ACKNOWLEDGMENTS

I am deeply indebted to all individuals who have assisted and supported me in this endeavor. The guidance, indulgence, and encouragement I received from them are deeply appreciated.

Sincere thanks to my supervisor Dr. Mohamed Al-Hussein for being a constant source of inspiration throughout this program. Thank you for believing I could succeed and for giving me the opportunity to do so.

Special thanks are due to my brother for encouraging me to pursue graduate studies in Canada and for supporting me through all the steps of the process. Thanks for helping me in making the right decision of selecting construction engineering & management group to pursue my career objectives.

Finally, I would like to thank my parents and my friends for their unending love, support, and encouragement during my study at University of Alberta and throughout my life.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION **1**

1.1 Piping Industry 1

1.2 Research Motivation 3

1.3 Research Objectives 5

1.4 Research Methodology 6

1.5 Report Organization 7

CHAPTER 2: LITERATURE REVIEW **9**

2.1 State of the art literature review 9

2.1.1 Applications of computer integrated construction (CIC) *9*

2.1.2 Applications of virtual 3D model for conceptual cost estimation *13*

2.1.3 Applications of Automation in pre construction activities (CAD/KBS) *15*

2.2 Current practices in the industrial piping construction 18

2.2.1 The current scenario *18*

2.2.2 New technologies in industrial piping *19*

CHAPTER 3: PROPOSED METHODOLOGY **22**

3.1 Introduction 22

3.2 Problem Definition 22

3.3 Challenges Involved 24

3.4 Proposed Methodology 27

3.5 Process Flow in the Proposed Methodology 30

3.6 The System Architecture 35

3.7 System Database 38
3.8 Integration with the developed Information Management System 41

CHAPTER 4: SYSTEM IMPLEMENTATION AND CASE STUDY 44

4.1 Introduction 44
4.2 Database Design 45
4.3 System Implementation 49
4.3.1 Step 1: The 3D Model 50
4.3.2 Step 2: The ISO Model 60
4.3.3 Step 3: Data Export to Information Management System 64
4.3.4 The Information Management System 77

CHAPTER 5: SUMMARY AND CONCLUDING REMARKS 87

5.1 Conclusion 87
5.2 Research Contributions 87
5.3 Recommendations for future research 88

CHAPTER 6: REFERENCE 90

LIST OF TABLES

Table 1: Current Practices in Design and Estimation 21

Table 2: Bill of Material for the Piping System Case Study 50

Table 3: Pipe Categories 83

LIST OF FIGURES

Figure 1: Typical Material Costs in Petrochemical Complex 2

Figure 2: Typical Field Labor Costs in Petrochemical Complex 3

Figure 3: Growth in Canadian Economy 4

Figure 4: Computer Integrated Construction Model 12

Figure 5: The ISOPEDAC System 17

Figure 6: The Information loss over the various project phases 24

Figure 7: The Proposed Methodology 28

Figure 8: The Plan Drawing 32

Figure 9: The Process Flow Diagram 33

Figure 10: The UDE File Format 34

Figure 11: The System Architecture 36

Figure 12: The ISOMETRIC Drawing 37

Figure 13: The Entity Relationship Diagram 40

Figure 14: The System Main Components 42

Figure 15: The Database Schema 46

Figure 16: List of Attributes of the 3D-CAD System in SQL 47

Figure 17: Sample Instances of the 3D-CAD system in SQL 48

Figure 18: List of Attributes of the IMS in SQL 48

Figure 19: Sample Instances of the IMS in SQL 49

Figure 20: The 3D Design Specification Options Dialog Box 51

Figure 21: 3D Design Options Dialog Box 53

Figure 22: 3D Design Riser Mode Dialog Box 54

Figure 23: Valve Placement Dialog Box 55

Figure 24: Select Pump Type Dialog Box 56

Figure 25: Enter Vessel Information Dialog Box 57

Figure 26: Column Details Dialog Box 58

Figure 27: Select Beam Type Dialog Box 58

Figure 28: Front Loaded 3D Design of the Pipeline 59

Figure 29: The UDE Export Dialogue Box 60

Figure 30: The Auto ISO Dialogue Box 61

Figure 31: The Cadpipe ISOLOG Report 62

Figure 32: Automatic ISOMETRIC Drawing generated by UDE file 63

Figure 33: DTS Package design in SQL 65

Figure 34: The Source Dialogue Box 65

Figure 35: The Select File Format Dialogue Box 66

Figure 36: The Specify Column Delimiter Dialogue Box 67

Figure 37: The Destination Dialogue Box 68

Figure 38: Transform Data Task: Source Tab 69

Figure 39: The Transform Data Task: Destination Tab 70

Figure 40: The Transform Data Task: Transformations Tab 71

Figure 41: The Transformation Options: General Tab 72

Figure 42: VB Script for Transformation Definition 73

Figure 43: The Transformation Options: Source Columns Tab 74

Figure 44: The Transformation Options: Destination Columns Tab 75

Figure 45: The Result of Package Execution 76

Figure 46: Data Transformation Process 77

Figure 47: Estimate Inquiry Dialog Box 78

Figure 48: Estimate Checklist Setup Dialog box 79

Figure 49: Estimate Take-off Checklist 80

Figure 50: Automated Estimation Results in Information Management System 82

Figure 51: The Data Flow in the Bidding Stage 84

Figure 52: Typical Estimation Man-Hours Break-up 85

CHAPTER 1: INTRODUCTION

This chapter provides a brief introduction of the industrial piping industry, its significance, and the past and current trends in the industry. Further, it introduces the 3D CADPIPE based system for project information and cost estimation in industrial piping projects. It also outlines the research motivation, objectives, methodology, and thesis organization.

1.1 Piping Industry

The life of an industrial facility, from concept to commissioning and beyond, involves almost all disciplines of engineering. So wide is the knowledge base requirement and so intricately integrated these inputs from various specializations are, that they make the conventional well defined engineering disciplines look artificial. The piping industry is a prime example of the complexity involved.

Piping systems are an essential and integral part of our modern civilization (Nayyar.M.L. 2002). Piping systems in an industrial facility are comparable to veins and arteries and fluids, vapors, slurries, solids etc. flow through them under various conditions as imposed by the process design of the plant. Piping systems find applications in water supply, natural gas, refineries, chemical plants, paper mills, food processing plants, fire protection systems, storm and wastewater piping and health facilities. Piping systems are subjected to almost all of the severest conditions of the plant such as high temperature, pressure, and flow, as well as, various combinations of these. Piping because of its nature requires a number of day to day decisions on matters of detail which in some ways are often more

difficult to solve than major issues connected with the project. It is this detail which can cause expensive delays in design and construction and consequently in commissioning. In almost all petrochemical industries the installed capital cost of piping is a major factor in industrial investment. Figure 1 and Figure 2 shows the typical field labor costs and typical material costs in Petrochemical Complex respectively.

Lost time in piping construction has an effect that goes well beyond its direct cost as it involves financial loss in proportion to the total industrial investment. A delay in or during start-up translates into idle capital and losses in earning capacity of the industry.

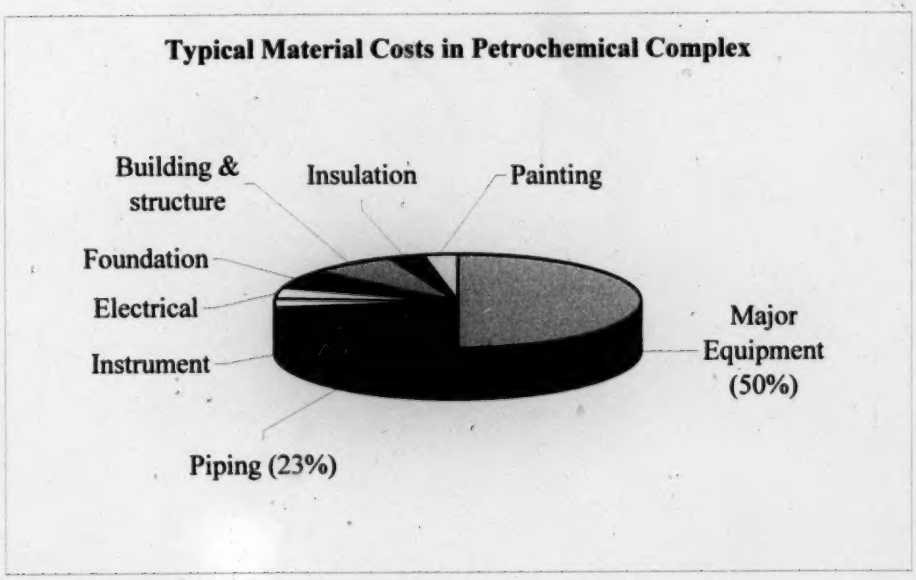


Figure 1: Typical Material Costs in Petrochemical Complex

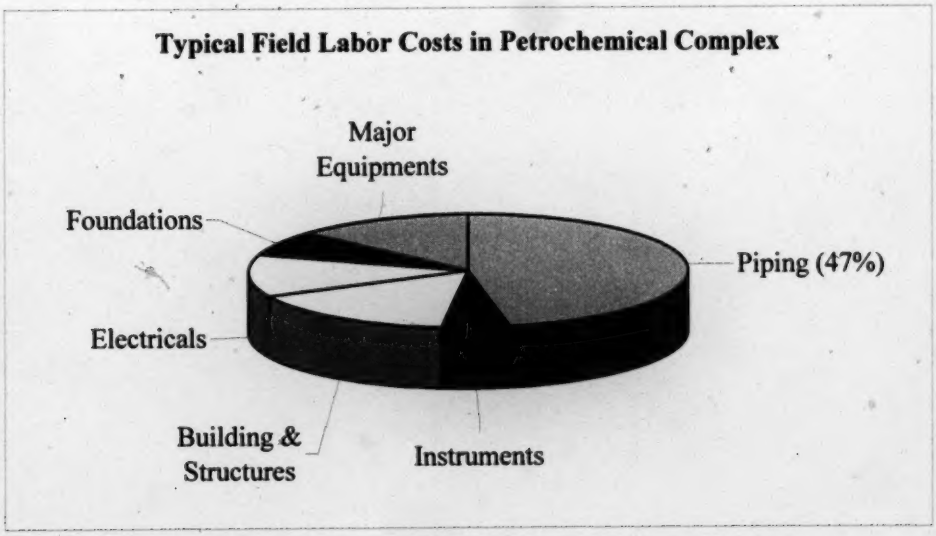


Figure 2: Typical Field Labor Costs in Petrochemical Complex

1.2 Research Motivation

The piping industry is an integral part of the Canadian construction industry. The Canadian economy is growing and the construction industry is playing a major role in that growth as evidenced by the rising Canadian Gross Domestic Product (GDP) illustrated in Figure 3. The construction industry accounts for approximately 5.34% or $53.12 Billion of the total GDP (Statistics Canada, Feb 2003).

Computer technology is being used extensively to obtain rapid solutions to the more complex problems of industrial design and project information in the industry. More recently, it is being used in the production of piping detail drawings, piping isometrics, bill of quantities (BOQ), cost estimations and control. Accurate cost estimation and bidding for a job in time is vital for any contracting company's survival in the current competitive

market. Contractors, in general, prepare bids for a variety of jobs at any given time, which can lead to expensive yet avoidable mistakes in the bid package. The bid package relies heavily on the accuracy of the quantity takeoff.

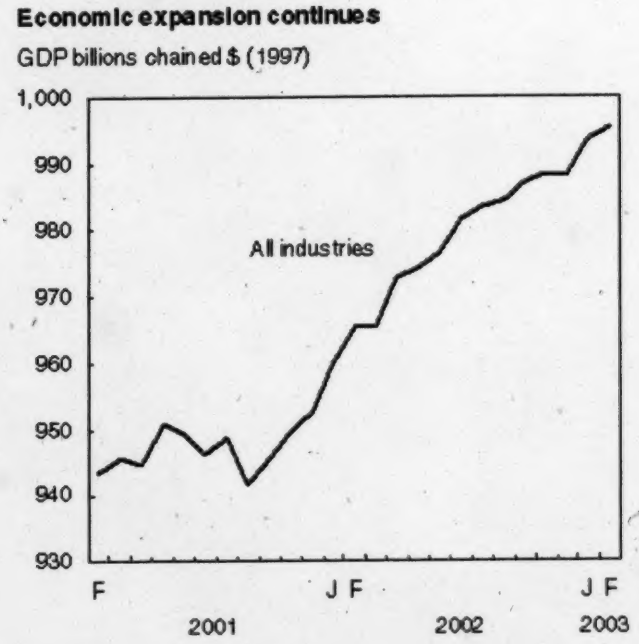


Figure 3: Growth in Canadian Economy

(Source: Statistics Canada, The Daily, catalogue number 11-001-XIE, Apr 30, 2003)

The current practice for quantity takeoff of piping varies vastly from company to company. Generally, contractors develop their own distinct methods to process the quantity takeoff. Some of the challenges faced by the industry include: manually feeding of data to the estimation software, locating the right off-the-shelf software, and avoiding paperwork and data redundancy. The manual process often causes unnecessary delays in the

decision-making process and is prone to human errors. Data integration is a major challenge for the companies that use customized or off-the-shelf software for estimation, planning and preparation of bid. Current approaches do not facilitate collaboration and communication between project participants (design, construction and estimation engineers).

This research presents a methodology to permit knowledge sharing between disciplines. The proposed methodology has been incorporated into a computer system that integrates information management system (IMS) with 3D-CAD model through a central database. Piping design software CADPIPE 2004 is used as the 3D-CAD model and SQL server 2000 is used as the central database to integrate it with the information management system developed by CEM group of the Department of Civil Engineering, University of Alberta. The developed system uses the Data Transformation System (DTS) package of the SQL server 2000 to address the integration and data transformation challenges faced by the piping industry, specifically, between the two disciplines of design and estimation. A case example is used in this research to demonstrate the effectiveness of the proposed methodology.

1.3 Research Objectives

This research is intended to bridge the informational gap between the designer, estimator and the construction engineer by providing a tool for sharing project information from different disciplines. The methodology minimizes redundant activities performed during

the estimation process by automating the quantity take-off process. The CAD model, prepared during the design stage, integrates with external databases of information management system using object-oriented methodology. This research capitalizes on 3D-CAD and databases that are familiar models to both designers and construction engineers. It also addresses the concept of construction integration at different levels: at the application level (communication between software), through a central database (project repository of information). The information management system is a customized product developed at University of Alberta to meet the requirements of the Alberta province environment. The current system assists practitioners in bidding, estimating and procurement process. This research is a continuation of this effort and aimed at:

- Integrating the 3D-CAD model with information management system to automate the quantity take-off process, generation of the shop/field drawings process and to assist in the organization of the bid preparation process.
- Minimizing the intra-disciplinary information gap between the designer, the estimator and the construction engineer
- Integrating applications through a central database for easy retrieval and processing of the project data.
- Building object oriented models for cross platform communication between 3D model and the information management system.

1.4 Research Methodology

To achieve the research objectives stated in the previous section, a *repository* of information within the domain of the 3D-CAD model is developed. An extensive literature review of historic and current systems is performed to verify the proposed methodology. Computer Integrated Construction (CIC), virtual 3D models for conceptual cost estimates and current practices of the design and estimating industry are also carefully analyzed. The challenge is to create piping designs using 3D-CAD to improve the quality of the drawings and front load it with process information. Finally the proposed methodology is implemented in the 3D-CAD environment using the CADPIPE 2004 software. Microsoft SQL server is used to develop the database and Data Transformation System (DTS) is used to integrate the 3D-CAD system with the information management system.

1.5 Report Organization

This report is organized into five chapters. **Chapter 1** (Introduction) describes the Piping Industry and its significance, the research motivation, and the problems faced by the industry. Further, it presents the research objectives of this project, details the methodology employed to achieve those objectives and outlines the organization of this thesis. **Chapter 2** (Literature review) covers an extensive study of the available research in this area and evaluates the various approaches to information management. Computer integrated construction and virtual 3D models for conceptual cost estimation are explored as well as other approaches. **Chapter 3** (Proposed methodology) presents a snapshot of the research

methodology used and an example that illustrates the data flow and other characteristics of the system. **Chapter 4** (System implementation and case study) describes the step-wise detail of the implementation process using a case study. The objective of this chapter is to verify the proposed methodology using an example. **Chapter 5** (Summary and concluding remarks) summarizes the research finings and presents a conclusion. It also describes the research contributions and recommendations for future enhancement of the 3D-CAD information system.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews the state of the art literature and current practices in the construction industry. Various points of views and concepts are discussed and compared. In addition, the various tools and techniques that are available to build a virtual reality model for construction cost estimation are discussed.

2.1 State of the art literature review

This groups the available literature in three broad categories that primarily focus on the state of the art knowledge developments in the following areas:

- Applications of computer integrated construction (CIC)
- Applications of virtual 3D model for conceptual cost estimation
- Applications of automation in pre construction Activities (CAD/KBS)

2.1.1 Applications of computer integrated construction (CIC)

Computer Integrated Construction (CIC) and various applications of this technique have been widely described in the literature (Choi et al. 1989, Williams et al. 1988, Tucker et al. 1986, Yamazaki 1991, Kangari et al. 1990). CIC is the adaptation of Computer Integrated Manufacturing (CIM) concepts in the construction industry. It is defined as a strategy for linking existing and emerging technologies and people in order to optimize planning, management, engineering, design, procurement and contracting, construction, and support functions.

CIC is being rapidly developing with the objective of sharing data and information among computer applications. CIC is replacing the traditional work process within Architecture, Engineering and Construction (AEC) with the electronic sharing of information. CIC is a solution to the ever-persisting problem of construction industry fragmentation. Integrating AEC computer applications can bridge these "islands of information" that are created by automating individual tasks. Productivity enhancement is directly related to the ability of reusing the information and not having to recreate it (Parfitt et al. 1994).

CIC links and integrates important information in several phases of the construction process (Vaha et al. 1997). The primary goals of CIC are: 1) rapid top-quality design; 2) fast and cost-effective construction; and 3) effective facility management (Teicholz and Fish 1994). Integration of design and construction is an essential requirement to achieve the primary goal of CIC (Kunigahalli 1997).

Currently the relevant CIC computer-based technologies include: Object Oriented Programming (OOP); Knowledge Based Systems (KBS); Data Base Management Systems (DBMS); Computer Aided Drawing/design (CAD) and visual computing; robotics and automated systems; Computer Aided Engineering (CAE); and Local Area Networking (LAN).

To structure a systematic approach for applying computer and automation techniques to design/construction modeling techniques have been used effectively. These modeling techniques have been viewed as a structured way to develop CIC by carefully investigating

the planning, design, and construction process. Modeling techniques provide a thorough understanding of how a CIC system works and allows identification of irregularity, duplication, and inefficiencies of the system. Major CIC modeling techniques are: physical, functional, information, simulation, and organizational modeling.

These models provide basic techniques that are necessary for the implementation of CIC. However, it should be noted that modeling CIC is very complex. These models can resolve only portions of the complex CIC problems and care must be taken to avoid misapplication of the modeling systems. Figure 4 shows an overall model of the CIC system. The model is divided into three major areas: 1) Integrated design/construction planning; 2) site automation system; 3) factory automation.

In today's industrial projects information technology is viewed as a cutting edge resource. CIC is a strategy that incorporates computers and robotics, to link existing technology with people in order to optimize business activity. There is no standard formula for CIC. A strategy for implementing CIC has not been formulated and each company must define its own system. Although CIC is effective it must be customized and adapted to meet company specific needs.

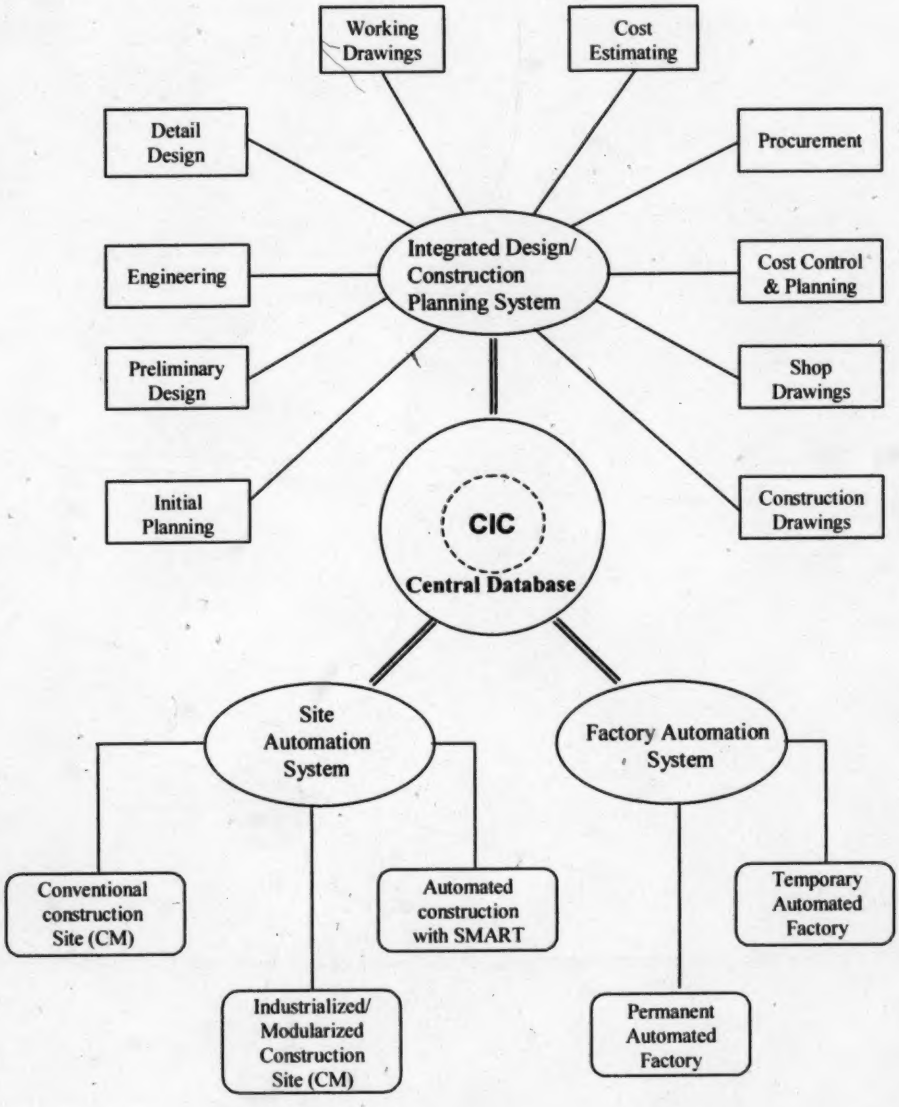


Figure 4: Computer Integrated Construction Model

(Source: Yasuyoshi Miyatake, Roozbeh Kangari (1993))

2.1.2 Applications of virtual 3D model for conceptual cost estimation

Conceptual estimation is an important phase of the construction project cycle. It assists owners and designers in making their decision to accept or reject a project prior to committing funds. The model integrates 3D-CAD drawings with relational databases in a Virtual Reality environment to animate building projects (Jrade 2000). The modularity allows a dynamic link between relational databases and 3D-CAD drawings so that a new conceptual estimate is automatically generated any time the drawing design is modified. Moreover, the preceding drawing once rendered can be viewed and animated on the web using Virtual Reality browser. Owners, cost engineers and estimators then have a tool that automates the preparation of conceptual cost estimates. 3D models not only allow one to visualize the project from any point in space, but also to actively eliminate errors at the point of design (Vaugn 1996). 3D modeling in a computer is a complex and challenging problem.

Efficient computer-based storage and manipulation of geometric information is necessary to develop the powerful CAD systems that are required for the rapid design process and cost-effective construction (Kunigahalli 1997). Many studies have been conducted in recent years recommending the integration of Virtual Reality (VR) and 3D technologies to simulate and model the construction process (Aouad et al. 2000). Geometric building data is stored in CAD systems such as AutoCAD. While it is possible to build up VR models from scratch within VR packages, transferring this data directly from CAD to VR

applications would be much preferred. Doing so would reduce the repetition of tasks in both CAD and VR (Whyte et al. 1998). The successful implementation of VR models would represent a momentous advancement in the process of sharing information on the web and generating conceptual cost estimates.

Jrade (2003) proposes a framework to model the preparation of conceptual cost estimates by applying relational databases, 3D-CAD modeling and Virtual Reality. Since the model integrates the above three parts, the proposed methodology is divided into three phases. The first phase consists of designing all the relational cost databases needed in preparing conceptual cost estimates. The second phase consists of customizing AutoCAD to fit the proposed model requirements and integrating 3-D CAD drawings with external databases in order to automate the preparation of conceptual estimates. The final phase involves exporting the 3-D CAD drawings to the Virtual Reality environment.

In recent years, with the enhancement of the Management Information System (MIS), many aspects of the construction processes have been simulated. Through the application of relational databases it is now possible to store different kinds of project data and information for future use. The development process is carried out using industry familiar software applications like AutoCAD, 3D Studio, MS Access, and Visual Basic, therefore, implementing the MIS model will result in quick and cost effective estimates. This model provides a simple, flexible, user-friendly system and minimizes the communication time involved in preparing the cost estimates. Data is readily available and accessible.

2.1.3 Applications of Automation in pre construction activities (CAD/KBS)

Mousa Tabatabai-Gargari (1999) proposed an approach for automating pre construction activities by integrated CAD/KBS. The integration of knowledge-based systems and computer-aided design systems can expedite the generation of design alternatives and improve the accuracy of the cost estimates; therefore, the effectiveness of pre construction activities can be improved.

Pre construction activities include design analysis, cost estimating, and value engineering. Preliminary cost estimates play an important part in pre construction activities. Owners want to know accurate construction costs up front to determine if they meet their budget. If estimated costs are more than expected the project usually is redesigned to reduce cost. Accurate preliminary cost estimates also are important in performing Value Engineering (VE) studies. The studies are performed on the basis of cost and if poor cost information is used VE evaluation is hampered (Parker and Dell' Isola 1991).

A Knowledge Based System (KBS), also called the expert system, is a computer program that emulates the problem-solving process used by human experts. A KBS contains the knowledge, experience, and judgment of experts and is well suited to solving problems where judgment and experience play an important role (Bell and Elzarka 1992). A wide range of KBS applications have been developed in the construction industry. As an integrated system it is linked to CAD software and database-management systems. When linked to CAD, a KBS has tremendous potential for automating the design process. CAD

has also been used widely in the construction industry but its use has been limited to drafting for so many years that it is sometimes referred to as computer-aided drafting. In fact, the CAD database contains a vast amount of information that can be used effectively in the construction process (Reinschmidt and Finn 1999, Morad and Beliveau 1991).

This intelligent CAD system requires the integration of CAD systems with database-management systems and KBSs. Such integration is becoming more and more feasible with the constant increase of power and capability of commercially available software products. The integration of KBS with CAD is of extreme importance when automating pre-construction activities as it frees the user from an overwhelming data entry load (Levitt 1990). By integrating KBS with CAD, the KBS system can automatically interrogate the CAD database for any required information and the recommendations of the KBS can be inserted automatically into the CAD model. Figure 5 illustrates an integrated ISOPEDAC model for automating pre construction activities. CAD technology has advanced sufficiently to be integrated with external KBS so that it could be used in several applications within the construction industry.

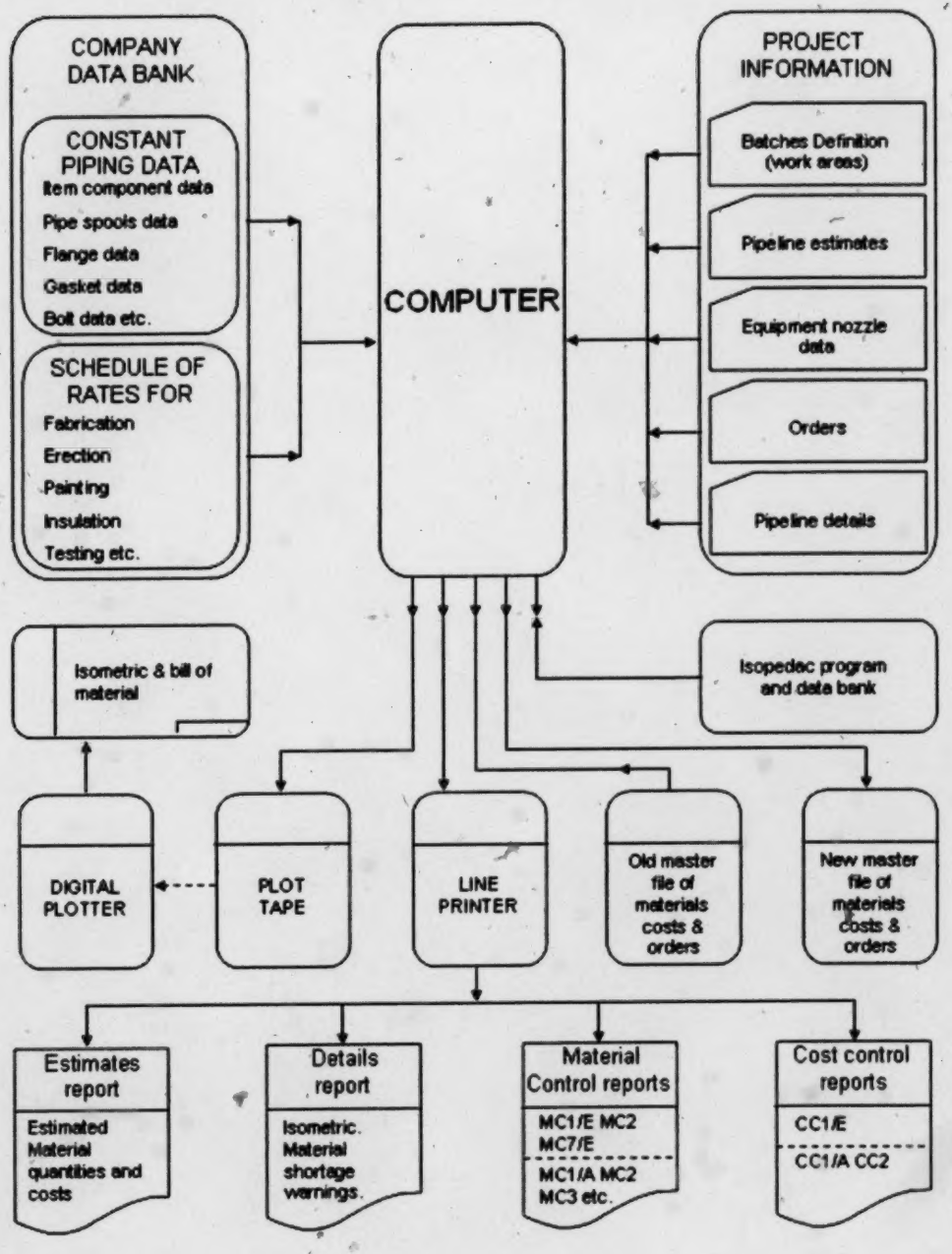


Figure 5: The ISOPEDAC System

2.2 Current practices in the industrial piping construction

This section discusses the various practices being followed by the piping industry. New technologies have provided the much needed direction to the growth in piping industry. Better and cheaper materials have opened new avenues for the piping applications. The overriding role of information technology in its capacity is to provide ready access to all information at all times, and to support much richer forms of communication and information sharing (Froes et al. 2001).

2.2.1 The current scenario

Industrial piping is a complex yet effective way to convey virtually all liquid and gaseous products over short and long distances. New materials and technologies are now enabling the piping industry to explore new application possibilities even in industries where fluid transport is not involved. These include electrical, electronics, building, construction, chemical, energy, and other industrial applications. The piping industry is an integral part of many industries including the building and construction (B/C) and rapid growth in these industries has increased demand for piping applications.

Increased market competition coupled with ongoing technical improvements in piping materials is fueling an already very competitive market situation. New materials, primarily plastics, are creating evolutionary and revolutionary changes in the industry. These new materials are cheaper, lighter, and better able to withstand environmental attacks such as corrosion. In addition, these materials are easier to install and maintain. Piping technology

and new applications will continue to be developed in the future. Inter-material competition is a way of life in a technologically advanced society but few industries have such a variety of competing materials. Pipes are made from materials ranging from inorganic clays, concrete, iron, and steel, to new high-tech plastics and alloys. The choice of a particular type of pipe is influenced by technical and often political factors. These factors impact a wide group of organizations and individuals in a multitude of areas including:

- marketing and management personnel in companies that produce, market and sell all types of piping and tubing, as well as, forming and installing equipment and parts, components, maintenance materials, and chemicals for cleaning and other uses;
- companies that supply, or want to supply, equipment and services to piping and tubing supply companies;
- financial institutions that supply money for such facilities and systems, including banks, merchant bankers, venture capitalists and others;
- personnel in end-user companies, communities and industries that purchase and use P/T equipment;
- government personnel that use piping in infrastructure building and develop and enforce piping standards

2.2.2 New technologies in industrial piping

Industrial piping has come a long way since it first began. As discussed in the previous sections, the introduction of computers has revolutionized the way piping design and estimation is carried out. Faster processors and more efficient software paved the way for the new technologies we have today. Piping design has seen tremendous growth in the drafting discipline, Features such as 3D/ISO drawings, walk through/virtual reality models, and automatic pipe routing, clash detection and stress analysis have made the design process faster and more reliable. Companies like Bentley, CAD Center, Intergraph, AEC, COADE and Alias Piping have contributed immensely with their revolutionary products in stress analysis and automated drafting software. Estimating techniques have also improved over the years and have become more sophisticated and accurate. The latest concepts and software have helped reduce the costs and the time required for the estimation process. Numerous attempts have been made in automating the estimation process and also in linking the estimation process with design but the challenge remains.

Table 1 illustrates and compares the progress made in the field of design and estimation. Some of the leading CAD software like ArchiCAD 7.0, AutoDesk's Revit & Architectural Desktop 2004 and Bentley Architecture 8.1 have proven to be more than just conceptualizing interoperability criteria and extracting information. Building Information Modeling (BIM). ArchiCAD was one of the first to successfully implement the Industry

Foundation Classes (IFC) standards developed by International Alliance for Interoperability (IAI) for 3D file data.

Table 1: Current Practices in Design and Estimation

Current Practice	
Design	**Estimation**
• Drafting softwares • 3D/2D/ISO drawings • Walk through models • Automatic pipe routing • Stress analysis of piping systems • Loads/Deflections under static/dynamic loading • Isometric extraction form 3D drawings • Clash detection capabilities	• Manually feed data to the estimation software • Customized or off the shelf software • Involves paperwork and data redundancy • Experience plays a major role • Prone to error • Poor integration with other softwares • Communication gap/delay

The new software uses object oriented technology that enables it to interact with analysis and estimating software such as Lawrence Berkeley Laboratories Energy Plus and Timberline Precision Estimating. In order to understand and apply these information solutions, familiarity with the CSI Master Format and UniFormat numbering systems, the IFC standard, and Open Database Connectivity (ODBC) format, is necessary.

CHAPTER 3: PROPOSED METHODOLOGY

This chapter discusses the proposed methodology of "Integrated 3D-CAD Information System for Estimation in Industrial Construction Projects", which is the governing concept behind the proposed system. A detailed description of the system and its components is presented with an example to illustrate the data flow and other characteristics of the proposed system.

3.1 Introduction

Attempts have been undertaken in the past to integrate the various disciplines in the construction industry. However, a truly integrated and efficient system that can read and interpret 3D-CAD drawings and then transform the data to an information management system is needed. In addition, a process to automatically do the takeoff and manage other related information is also required. In the following sections the problems faced by the industry are defined and the challenges are discussed followed by the proposed methodology.

3.2 Problem Definition

The efficiency of a construction project is determined by the effectiveness of the specific model used to communicate information. Architects use 2D or 3D CAD models to develop a project design; construction engineers use management tools such as CPM and PM software to assist in project control and integration phases. Estimators typically use some in-house developed spreadsheets or off-the-shelf software. Today, we rely solely on the

project participants' own ability to interpret these discipline-specific models in order to form a mental picture of a proposed design and its corresponding construction approach. These discipline-specific models contribute to misinterpretation and increasingly result in construction site errors and rework, as well as, the subsequent loss of productivity and increase in costs. Advanced computer tools can be used to prepare designs that integrate these discipline-specific models in order to coordinate cross-disciplinary tools used for design, construction, and facility management decisions. Integrating these discipline-specific models with lean thinking concepts will identify and minimize non-value adding tasks. As identified earlier, information management is the key to the success of any project. Loss of information over the life of project is another matter of concern. Figure 6 illustrates the cumulative information transfer over the project's life cycle.

The information loss over the various phases is critical for the project operation and maintenance. Lack of sufficient data can hamper project's day-to-day maintenance or expansion work and can result in increase in cost and time. The storage of project data in a central database can allow all the project participants to access historic and current data of a project in a central location, ensuring consistency, integrity, and accuracy.

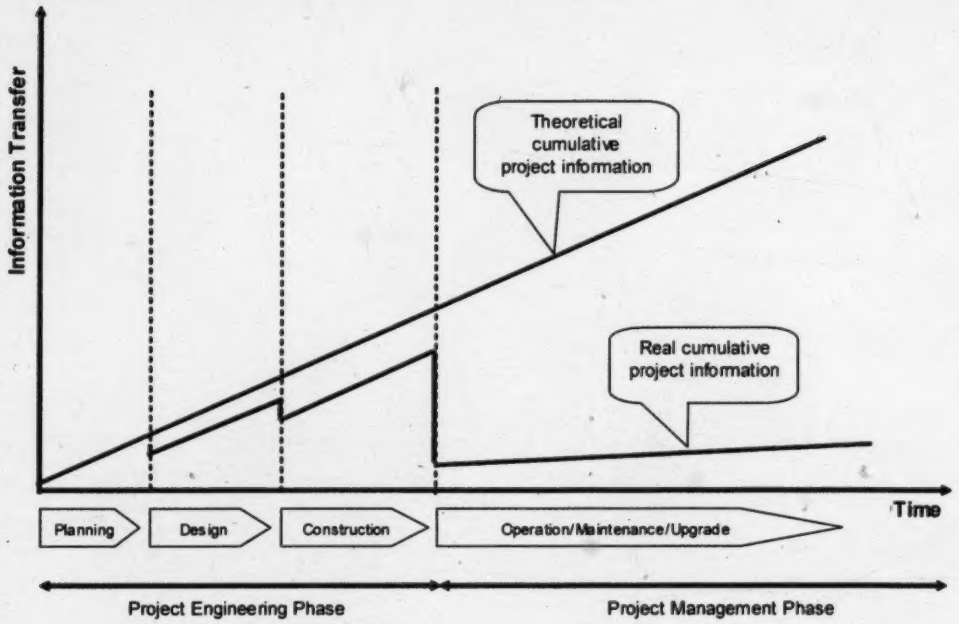


Figure 6: The Information loss over the various project phases

3.3 Challenges Involved

The development of the integrated 3D-CAD system involves the identification of the problem and the development of a methodology that permits better collaboration and communication between the various disciplines. Apart from the conceptual challenge of integrating the system components, the primary challenge is the technological integration of the various software being used. Each organization has its own unique system for managing projects and the challenge is to develop a robust and generic methodology that can be applied and successfully used by most industries. Generally, contractors develop their own distinct methods to process the pre-bidding activities, methods that might include using off-the-shelf software. The process involves extensive paperwork and data

redundancy, which can cause unnecessary delays in the decision-making process. Adopting a new technology is also a matter of concern as it involves additional training and implementation time. Therefore, a new technology should be easy to use yet powerful enough to integrate the various systems and achieve the objectives.

The analytical difference between a designer and a contractor is listed in Table. The designer views the valve as a conductor for the two-inch pipe. A contractor, however, needs to estimate the labor required to weld this valve in the shop, remove it for a hydro test, and weld it again (pipelines are tested to withhold higher pressure than the pressure rate for which they are designed. As a result, valves have to be removed during the test and then welded again). The designer views a pipe as Carbon Steel (CS) material having definite dimensions and ratings. However, a contractor may view a pipe in terms of the job type and hydro testing requirements of the pipe once it is welded. Each piping component on the drawing has a cost factor attached to it and the contractor has to consider this before procurement and execution. The system intends to bring these cost factors to the designer's consideration during the design phase itself, which can optimize the design process.

Table 2: Analytical difference in data interpretation

Owner/Designer's Interpretation	**Product: Gate Valve** Material: CS Line #: CS001 Diameter: 2 Inch Pressure Rating: 3000lb	**Product: Pipe** Material: CS Line #: CS001 Diameter: 2 Inch Thickness: Sch 80 Length: 4 ft Hydrotest: 45 Kg/cm2
Contractor's Interpretation	**Product: Gate Valve** Material: CS Line #: CS001 Diameter: 2 Inch Pressure Rating: 3000# Weld: 2 (Shop) Man-Hours: 0.5h/Weld Hydrotest Details: Product: Spool / Blind Material: CS Diameter: 2 Inch Thickness: Sch 80 Length: 3.2 Inch Job required (Field) Man-hours 1) Cut valve: 2 0.05 h 2) Weld spool: 2 0.2 h 3) Cut spool: 2 0.05 h 4) Weld Valve: 2 0.2 h	**Product: Pipe** Material: CS Line #: CS001 Diameter: 2 Inch Thickness: Sch 80 Length: 4 ft Hydrotest: 45 Kg/cm2 Job Type: Shop Man-Hours: 0.02h/ft Hydrotest Type: Field

The Object-Oriented Programming concept of inheritance and encapsulation of data is employed as the underlying data model for representing the construction process and combining the above-listed information and its interactions. The function of encapsulation of data is applied to set the hierarchy level of processes. 3D-CAD solids represent the physical objects within the CAD model. Integrating the 3D-CAD solids with the external data models makes the CAD-drawing a *repository* of information that can be manipulated while building the actual design-construction process model. 3D-CAD solids are thus a

superior alternative for object handling when utilized as a medium of analysis, experimentation, and communication.

3.4 Proposed Methodology

The previous sections describe the importance of better collaboration and communication between the various project phases and participants and the need for storing project data in a central database for future use. This research presents a methodology for an automated quantity take-off system from the 3D-CAD model to the information management system using a central database for storing project information. The central database of the project data ensures easy access, retrieval and update of the project information by all the project participants. Figure 7 depicts the proposed methodology of the 3D-CAD information system.

The Integrated 3D-CAD model is the central component of the entire system. A designer can develop a project using the 3D-CAD model, which represents a set of predefined objects. Each object, when added to the drawing, is described by the three levels of the hierarchy including material type, resources, and scope of work. Properties of these objects represent the model database schema.

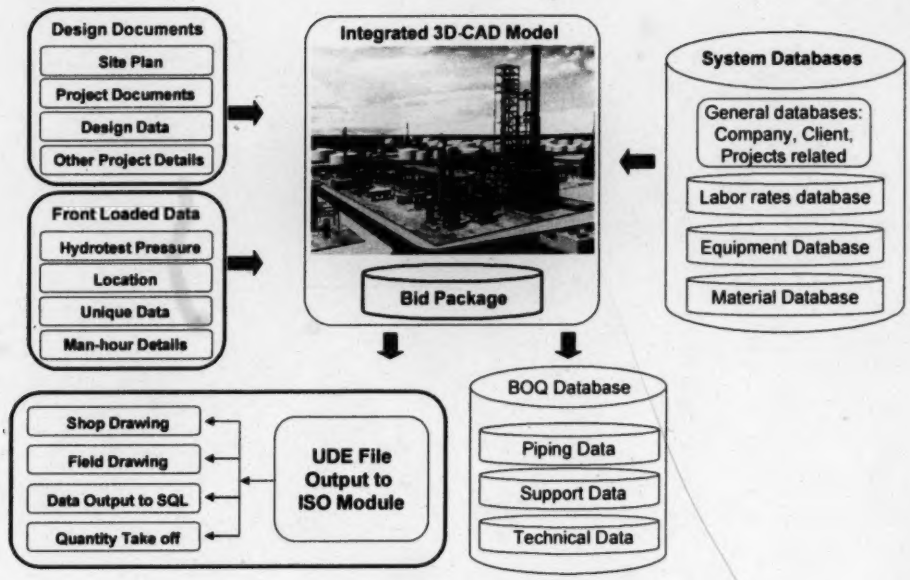


Figure 7: The Proposed Methodology

The input to the system is design documents that may contain site plan, project documents, design data and other related information. This methodology front-loads the critical and item specific data to the 3D-CAD drawing generated by the 3D-CAD information system. The front-loading of data here means the additional item specific data such as hydrotest details, man-hour details and other instructions, that might be later used by the estimator or the construction engineer. This ensures that the designer is also aware of the cost implications of his design. Each 3D-CAD drawing generated from the 3D-CAD information system has additional front-loaded data, such as, hydrotest pressure, location, man-hour details etc. Therefore, the construction engineer receives a *virtual repository* 3D-CAD drawing. This model can be used at all stages of the project as all necessary

information is held in the model including isometrics, details, support data, elevations, 3D cut-away sectional views, material estimates etc. Changes are communicated by modifying the digital values of the object's attributes as stored in the database. The 3D-CAD information system implements the company specific information, policies, rates and other details through a central systems database.

The output of the central integrated 3D-CAD information system is categorized in two distinct phases. The first output is the typical project data to the Bill of Material (BOM) database. This database is created using the SQL server 2000 for the project specific bill of quantity data in the information management system. It typically includes piping, support and other technical data related to individual 3D-CAD drawings generated by the 3D-CAD information system. The other output of the 3D-CAD information system is the Universal Data Exchange (UDE) file to the Isometric (ISO) module. The universal data exchange file is a unique file for each of the drawings generated. It contains the basic design data that can be interpreted by the ISO module to automatically create an isometric drawing from the UDE file. This isometric drawing has additional special instructions from the designer about pipe handling and installation data from the integrated 3D-CAD information system. The isometric drawing can later be automatically converted to shop drawings, field drawings, and then can serve as data input to the SQL server and quantity take-off process. Through this integrated system the data redundancy problem can be effectively addressed as the drawing is generated only once by the designer. The same drawing is utilized

effectively in the subsequent processes till it reaches the construction engineer or project estimator. Further, since this system is integrated with the already developed information management system, the same data can be used for procurement and control as well.

3.5 Process Flow in the Proposed Methodology

In real life scenario, after a project is conceptually approved, the planning phase begins. Preliminary drawings and Block Flow Diagrams (BFD) are prepared along with preliminary schedules and budget. Next, in the development phase, BFD is converted to Process Flow Diagrams (PFD) by acquiring additional information about the project. Accurate budget, schedule and cash flow reports are prepared in this phase. Based on this information a project go/no-go is decided. Next, in the execution phase, Engineering Procurement and Construction (EPC) are carried out on the project. A designer's work start after the process is finalized. Block flow diagram (BFD) and process flow diagram (PFD) forms the basis of designers work. These diagrams provide the basic process information. Based on BFD and PFD, a Piping and Instrumentation Diagram (P&ID) is developed.

A P&ID provides detailed information about the process such as flow media, pressure, and temperature at various stages of the process. These details are used to calculate pipe size and other characteristics of it such as material, support type, design pressure etc. The design pressure establishes hydrotest or pneumatic test pressure as required by a piping system. Other details are also developed to control the flow and meet process requirements, if any. P&ID with other site constraints are used to develop the site plan and plan drawing

of a piping system. Figure 8 shows a typical plan drawing of a piping system. This plan drawing has elevations, fittings and control details of the piping system to be built. A designer uses 3D-CAD tool to create a virtual 3D model to visualize the complete piping system. Figure 9 shows the process flow in the proposed system.

The process starts by the creation of the 3D-CAD drawing using the available project information. Detailed information about the process and standards are incorporated using the system database, leading to the completion of a preliminary 3D-CAD drawing. Upon completion of the drawing in the CAD environment, the designer checks it for accuracy.

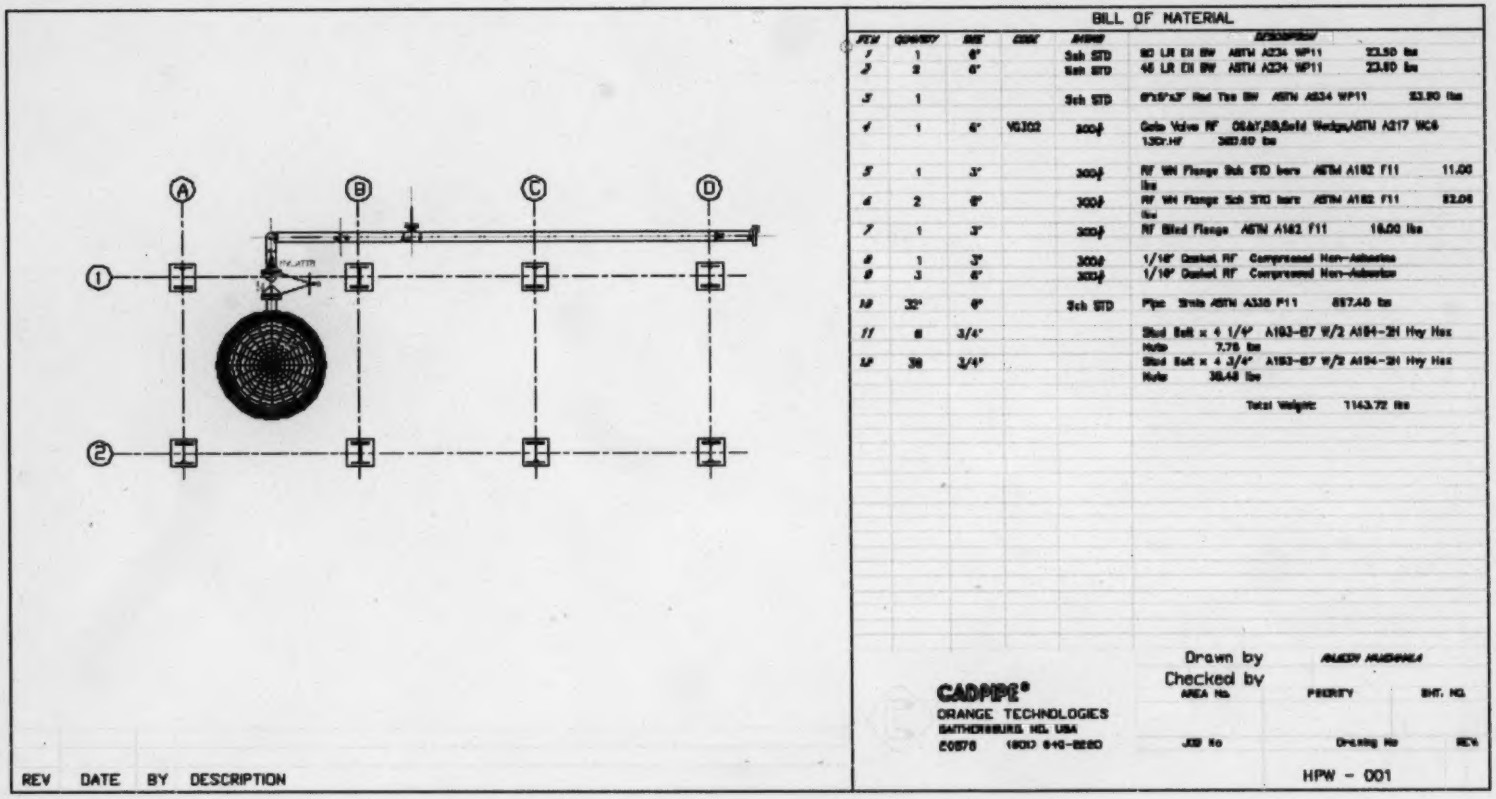


Figure 8: The Plan Drawing

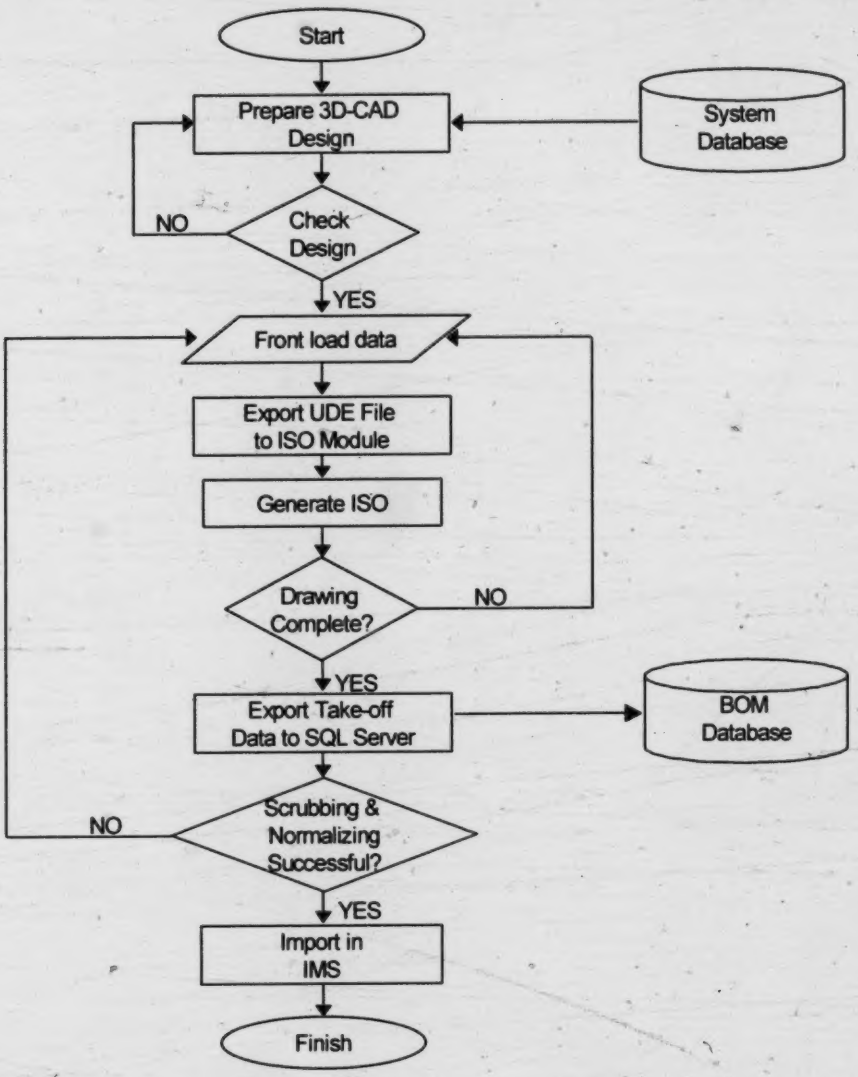


Figure 9: The Process Flow Diagram

Completed drawings are front loaded with data that might be useful for the project estimator or the construction engineer. The finished 3D-CAD drawing is exported to the ISO module in the UDE file format. A UDE file is a generic file that contains design data for future reproduction and processing of the drawing. Figure 10 shows the format of the

UDE file. The file contains details about the origin of drawing along with detail design data for each entity on the drawing. These details enable the ISO module to regenerate the 3D-CAD drawing in the ISOMETRIC format.

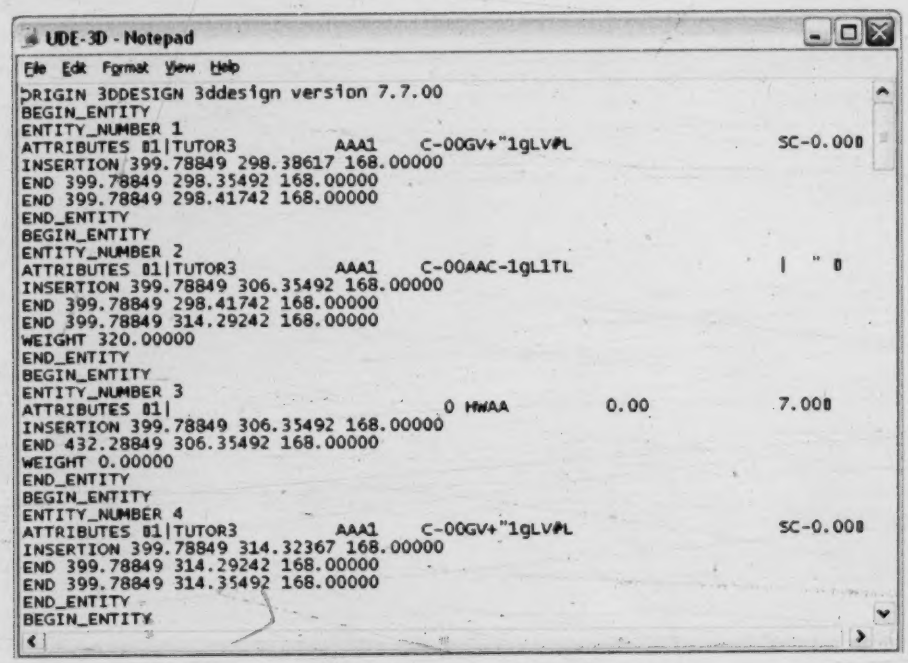


Figure 10: The UDE File Format

The designer checks the regenerated isometric drawing for accuracy and orientation. Minor modifications such as clarity of dimension lines, orientation of drawing etc. are carried out to ensure that the drawing confirms the company standard. The completed isometric drawing is automatically converted to the shop drawing or field drawing based on the user input and requirements. The shop/field drawing uses isometric drawing as the basis for drawing generation and adds shop/field details to modify it.

The completed isometric drawing has bill of materials (BOM) integrated into it. This BOM along with project data is exported as ".csv" file (comma delimited format file) to the BOM

database in the information management system. Scrubbing and normalizing ensures data compatibility with the already developed information management system by the construction engineering management group at the University of Alberta. Upon successful completion of this process the data is imported into the quantity take-off application of the information management system for checking data integrity and further processing. This automated transfer of bill of material replaces the current manual system of the information management system. This means the quantity take-off details in the application is automatically populated from the 3D-CAD information system. The integration of the processes mentioned in this section provides an efficient and time saving method for generating quantity take-off from 3D-CAD drawings and a better communication tool between disciplines.

3.6 The System Architecture

The system architecture of the developed system is shown in Figure 11. The main process of the system is log file generation, which is implemented using SQL Server 2000 in the central database. The log file is generated with scheduling, project plan, shop and field drawings. These details assist in preparing the bid summary for any given project.

The data from the central module is shared with the 3D module and vice versa. The 3D module processes the project related data and shares data with the ISO module to create 3D drawings, isometrics, fittings data and also stores current and historical data for future use. In the future development of the system this data along with the central module data can be collaborated with the actual construction data. The data flow in this system will permit the calculation of productivity, scheduling, built data and other estimates.

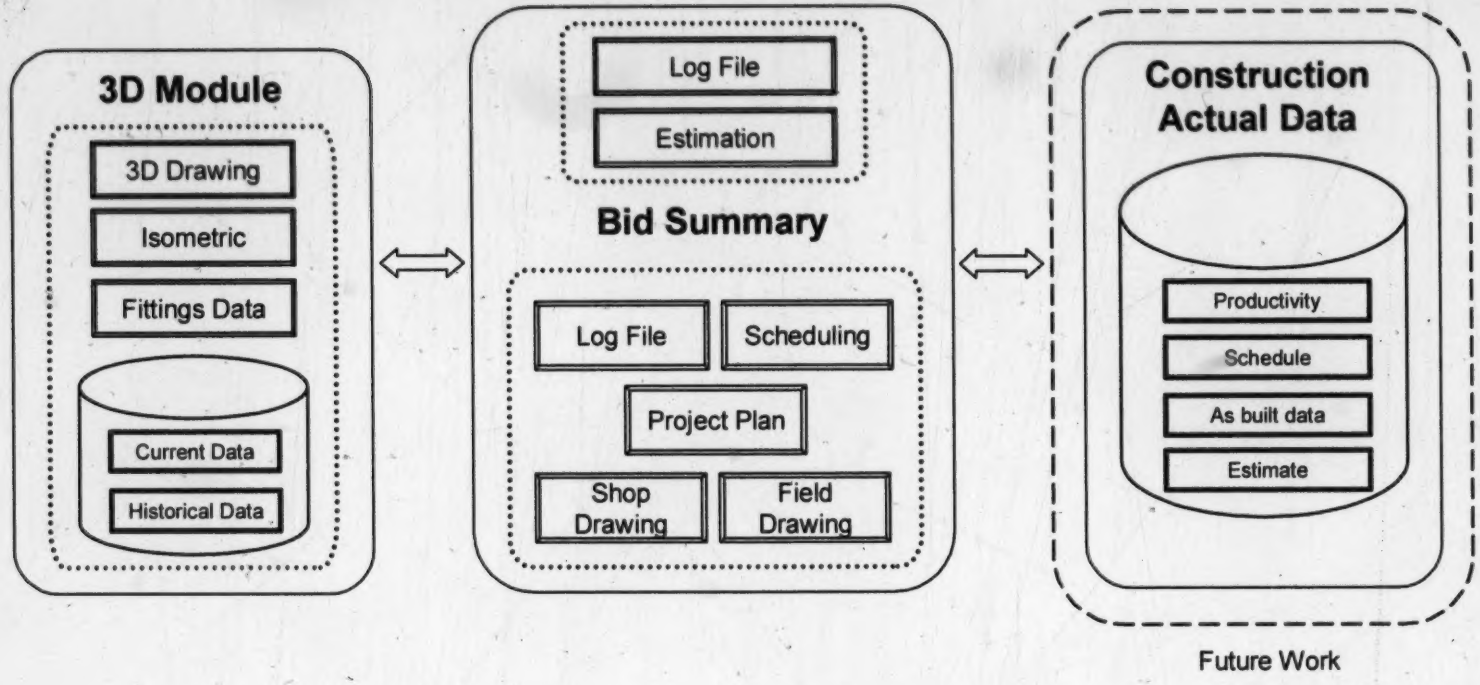
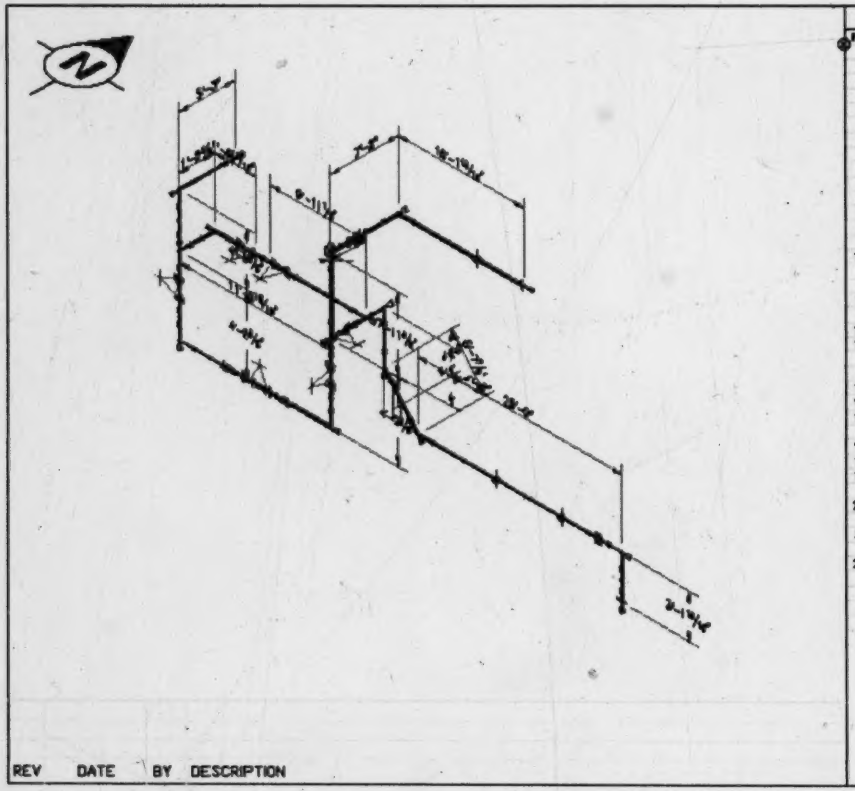


Figure 11: The System Architecture



BILL OF MATERIAL

ITEM	QUANTITY	SIZE	CODE	RATING	DESCRIPTION
1	2	3"		Sch STD	90 LR Ell BW ASTM A234 WP11 8.36 lbs
2	2	6"		Sch STD	90 LR Ell BW CS A234-WPB 47.00 lbs
3	6	6"		Sch STD	90 LR Ell BW ASTM A234 WP11 117.60 lbs
4	1	6"		Sch STD	45 LR Ell BW CS A234-WPB 23.80 lbs
6	1			Sch STD	6"x3" Conc Red BW ASTM A234 WP11 17.40 lbs
8	1			Sch STD	6"x6"NOT Red Tee BW ASTM A234 WP11 47.88 lbs
7	1	3"	VG302	300#	Gate Valve RF OS&Y,BB,Solid Wedge,ASTM A217 WC6 13Cr.HF 158.00 lbs
8	1	6"	VG301	300#	Gate Valve RF OS&Y,BB,Solid Wedge,A216-WCB 13Cr.Tr. 330.00 lbs
9	1	6"	VG302	300#	Gate Valve RF OS&Y,BB,Solid Wedge,ASTM A217 WC6 13Cr.HF 540.00 lbs
10	1	3"	VL302	300#	Globe Valve RF OS&Y,BB,ASTM A217-WC6 13Cr.Tr.HF 230.00 lbs
11	4	3"		300#	RF WN Flange Sch STD bore ASTM A182 F11 44.00 lbs
12	4	6"		300#	RF WN Flange Sch STD bore CS A105 164.00 lbs
13	8	6"		300#	RF WN Flange Sch STD bore ASTM A182 F11 246.00 lbs
14	7	3"		300#	1/16" Gasket RF Compressed Non-Asbestos
15	4	6"		300#	1/16" Gasket RF Compressed Non-Asbestos
16	8	6"		300#	1/16" Gasket RF Compressed Non-Asbestos
17	10'	3"		Sch STD	Pipe Smls ASTM A335 P11 72.52 lbs
18	35'	6"		Sch STD	Pipe Smls A53 Gr.B 652.64 lbs
19	45'	6"		Sch STD	Pipe Smls ASTM A335 P11 538.60 lbs
20	56	3/4"			Stud Bolt x 4 1/4" A193-B7 W/2 A194-2H Hvy Hex Nuts 54.46 lbs
21	48	3/4"			Stud Bolt x 4 3/4" A193-B7 W/2 A194-2H Hvy Hex Nuts 51.31 lbs
22	72	3/4"			Stud Bolt x 4 3/4" A193-B7 W/2 A194-2H Hvy Hex Nuts 76.97 lbs
					Total Weight: 3802.18 lbs

Drawn by RAJESH KANSAKALA
Checked by
AREA No. PRIORITY SHT. NO.

CADPIPE®
ORANGE TECHNOLOGIES
GAITHERSBURG, MD. USA
20878 (301) 840-2220

JOB No. Drawing No. REV.

CASE STUDY

REV DATE BY DESCRIPTION

Figure 12: The ISOMETRIC Drawing

This 3D-CAD information system architecture assists in preventing interference and battery limit problems of this system with other systems. Battery limit is the geographical, physical or theoretical contour of a work. It is defined in order to identify the limits of services, supplies or responsibilities for the part of a contract or a plant. The 3D model along with the process information is used to create an isometric drawing. A piping isometric drawing contains all the information from the piping plan drawing and is represented in an orthographic view. An example of this drawing is shown in Figure 12.

The process model developed in the 3D-CAD modeling environment provides the project participants with the ability to interpret these multi-discipline models in order to form a computer-simulated picture of a proposed design and its corresponding construction approach. The model assists construction engineer to prepare cost estimates, schedule fabrications and on-site utilization of the construction elements. Shop fabrication and field erection drawings can also be derived from the imbedded information in the CAD drawing.

3.7 System Database

The system database is developed in two phases: the design phase of the conceptual schema, and the implementation phase. The implementation of the conceptual schema is discussed in the next chapter. The development of the conceptual schema begins with identifying system requirements, data collection and its analysis. End user requirements and functional requirements are considered in identifying the system requirements, data collection and analysis of the database. This results in concisely written set of user requirements. The conceptual schema is developed using the Entity Relationship Diagram (ERD) following the procedure described by Elmasri and Navathe (1994). The proposed conceptual schema was implemented using Microsoft SQL Server 2000. Microsoft Visual

Basic 6.0 was used as the front end to create a user interface to control the data integrity and to implement hierarchical policies that, for example, determine the level of access rights of the contractor's organization. Microsoft SQL Server 2000 was used as the Relational Database Management System (RDBMS) back end of the application.

As discussed in the previous sections, the project data is stored in the central SQL server database. The developed SQL system architecture allows the data to be stored in various project specific and area specific databases. It has the inbuilt technology to store the current and historical data with lessons learned that could be used as a knowledge management tool for future projects. These ER diagrams consist of *entities*, *relationships*, and *attributes*. Objects are described as physical (such as pipe, support, valve, etc.) or conceptual (such as schedule, specification, etc). Attributes can describe the objects' properties. For instance, materials are described by type, size, and method of construction. Relationships are used as object connectors in order to address issues related to integrations with other systems such as CAD. ERD models are capable of capturing the structure of a construction process.

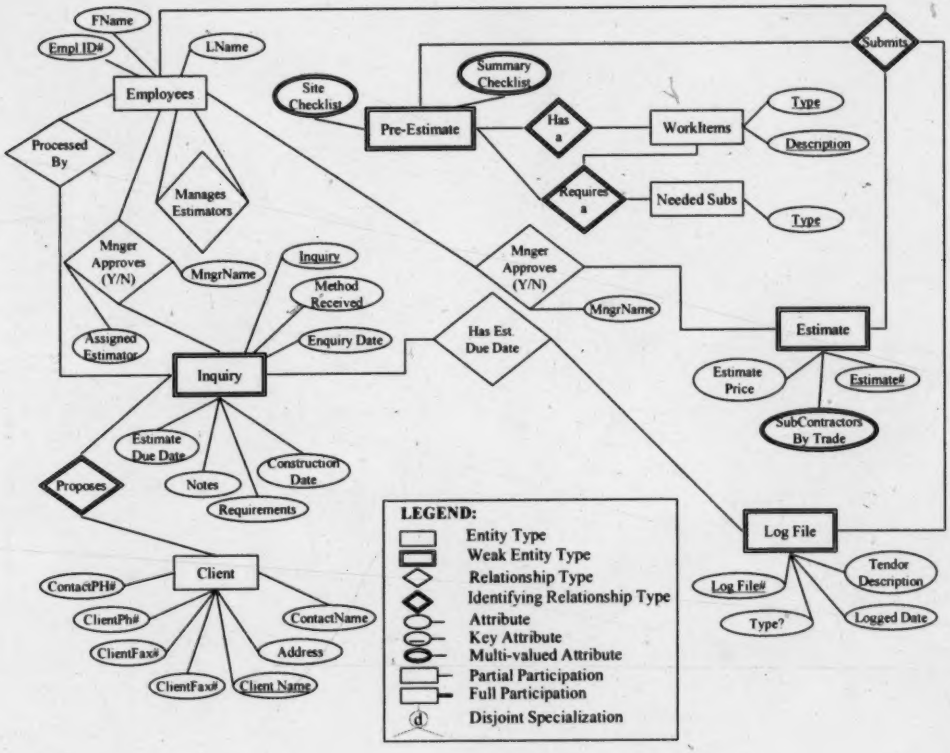


Figure 13: The Entity Relationship Diagram

Figure 13 represents the Entity Relationship Diagram (ERD) of the SQL database for the information management system. The ERD is an effective communication tool for estimators and system developers. The transparency of the diagram allows system developers to visualize the relationships between entities and attributes. The main attributes of this system are log file, client, inquiry and estimate. Entities are basic objects with an independent physical or conceptual existence. Each of these entities has their corresponding attributes to define the entities details and attributes are the particular properties of the entity type. This entity relationship diagram uses various types of attributes such as composite, simple, multi-valued, derived and key attributes as shown in

the legend. The key attributes such as log file # and estimate # represent the uniqueness of the attribute for the particular entity. Weak entity type is used for inquiry, estimate and log file entities whereas, multi valued attributes is used for subcontractor by trade, summary checklist and site checklist. Multi valued attributes represent a combination of attributes that individually contribute to the uniqueness of the multi valued attribute. Normal relationships and identifying relationships were used to connect the various entities. An example of identifying relationship is the relationship between entity client and inquiry.

3.8 Integration with the developed Information Management System

The integrated 3D-CAD information system was developed primarily to supplement and enhance the information management system developed by the construction engineering and management group at the University of Alberta. The 3D-CAD information system was integrated with the information management system using the architecture of data transformation services (DTS) module of Microsoft SQL server 2000. DTS is a collection of utilities and objects that allow you to import, export, and convert data from any data source to any data source, whether to/from another database system (heterogeneous) or to/from another SQL server. DTS can move SQL server objects, execute programs, File Transfer Protocol (FTP) files, and even has the flexibility to be expanded with custom communication (COM) components (Chaffin et al. 2004). Data mapping and transferring in DTS is achieved by using "Transform Data Task". This task allows data transformation from any Object Linking and Embedding Data Base (OLEDB) compliant data source to any compliant data source. The main advantage of DTS is automatic mapping of columns between the source and destination data sources. The DTS logic for this automated mapping of columns first weighs column name then ordinal column location to decide

how the column should be mapped. Limitations of DTS include inability to map data between columns having two different data types, in such cases manual data transfer is appropriate.

Figure 14 illustrates the system main components of the proposed methodology, which consists of the following four main components: 3D-CAD module, ISO module, Quantity take-off module and Cost/Schedule control module which is proposed to be added in the future enhancement of the proposed system.

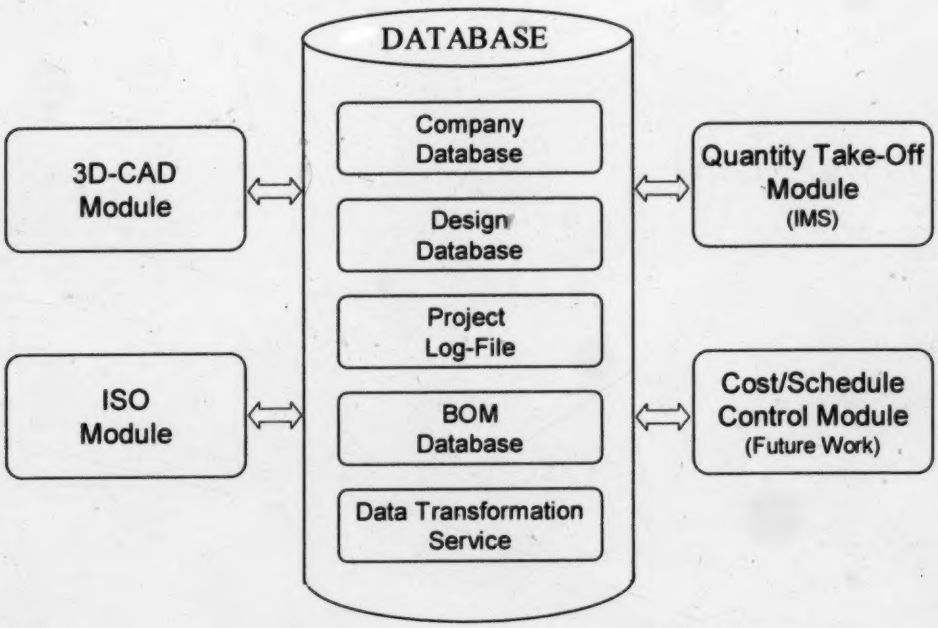


Figure 14: The System Main Components

The framework of the data transformation services allows the raw data from the 3D-CAD information system to be scrubbed and normalized and then exported to the information management system. Scrubbing the data is an essential step before exporting the data. Raw data has many unnecessary details that make it incompatible with the existing

database structure. For example, take-off data columns in the source table are not compatible with the destination columns, hence the columns ends2, wall_sch1, wall_sch2, seam, size2 is removed from the selected columns to be transformed. Normalizing the data ensures that the data types used in the scrubbed data are the same as the data types in the information management system. Once the data is exported to the existing databases in the information management system, the estimation module automatically picks up the new data and displays it to the user. The user can then access the information for further processing of the inquiry and other associated requirements.

CHAPTER 4: SYSTEM IMPLEMENTATION AND CASE STUDY

This chapter discusses the implementation process of the proposed methodology using a real life example. This process verifies the proposed methodology and checks the hardware and software requirements for the system. This chapter also discusses the advantages and shortcomings of the 3D-CAD information system along with the actual advantages of the developed system in the quantity take-off process.

4.1 Introduction

The previous chapter discussed the proposed methodology for the 3D-CAD information system which was developed to compliment the information management system developed by the construction engineering and management group at University of Alberta. In this chapter the proposed methodology is implemented with the help of an example to demonstrate the system capabilities. To achieve process innovation, productivity improvement, or elimination of non-value adding tasks, relevant information has to be captured within the modeling environment as described in earlier chapters. Current CAD models contain mainly geometrical information; such information alone is insufficient for modeling a construction process. Additional information is required including the scope of work, material types, specifications, logic, method of construction, and specific needs of each discipline.

The development of the 3D-CAD information system for estimation in industrial piping projects is intended to address these very issues. To verify functional performance of the developed system it is important to apply the concepts and technology in a real life example. The chosen example represents most of the aspects of piping and pipe fittings. The example has a pipe with elbows (both 45^0 and 90^0) connected to both a pump and a

vessel. This pipe has a valve installed along the run with a flange joint. All these details are captured by the developed 3D-CAD information system and the data is exported to the SQL database of the information management system developed by the construction engineering and management group at the University of Alberta. This system represents a typical pipe run in any industry. To store the take-off data in central SQL database, the database has to be designed, which is discussed in the following section.

4.2 Database Design

The first step in the development of the system is to develop a database schema that can process the enormous amount of data being read and communicated between the modules. In order to develop such a system it is necessary to determine and analyze the requirements of the database. Once all requirements are collected and analyzed a conceptual schema for the database is designed using a high-level conceptual data model. The data requirements of the system are defined concisely and include detailed descriptions of the data types, relationships, and constraints.

Further, the conceptual schema is implemented using the Microsoft SQL Server 2000 database system. The design process incorporates the development of a set of specifications and the conceptual schema of the database. The design of the schema focuses on the development of an entity relationship (ER) diagram following the procedure described by Elmasri and Navathe (1994). The development of entity relationship diagram for the information management system is discussed in detail in the previous chapter.

Once the database schema is established the relational model concept is built to implement the database schema. The relational model represents the data in a database as a collection of relationships (Elmasri and Navathe, 1994). A relationship can be viewed as a table of

values; each row in the table represents a collection of related data values. These values can be interpreted as a fact describing an entity or a relationship instance. The table name and column names are used to interpret the meaning of the values in each row of the table. Based on this concept the database structure and the tables were built in SQL database. The tables were checked for the data integrity and linked to each other following the relationships established in the entity relationship (ER) diagram. The relationship schema can be interpreted as a declaration or a type of assertion. Figure 15 is a snapshot of the database schema created. Each of the tables is created from the logic defined in the entity relationship diagram. The primary and secondary keys are defined for each table and the integrity constraints are implemented.

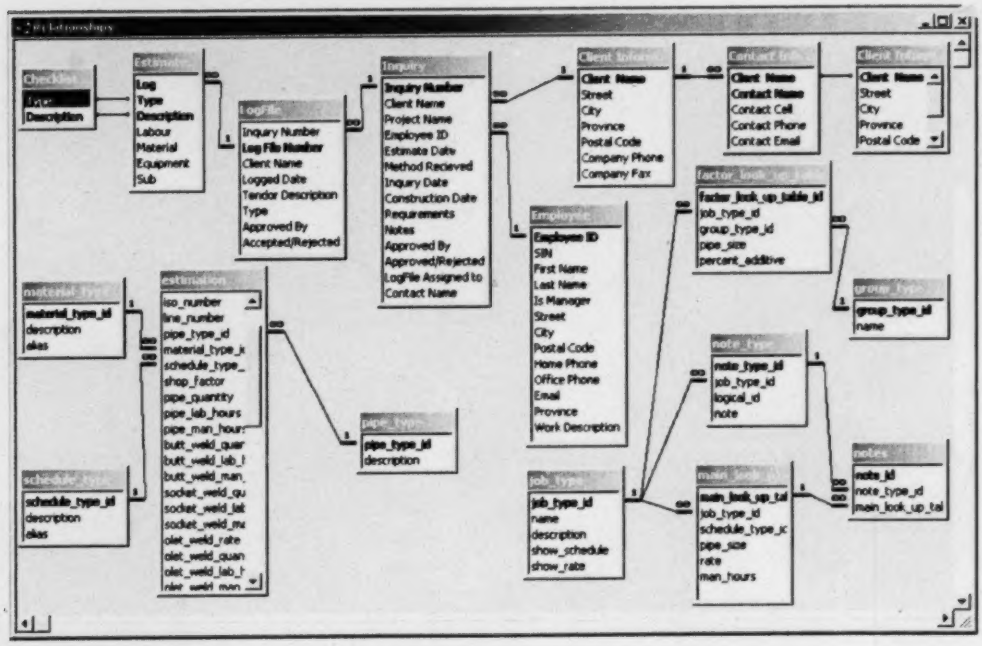


Figure 15: The Database Schema

The design data in the 3D-CAD system has sixteen attributes, which are, Drawing_Name, Item_No, Quantity, Pipe_Size, Schedule_Rating, Shop_Field, Tag, User_Code, Short_Description, Long_Description, Line_Number, Material_Spec, Revision_No, Weight, Instructions and Comments. These fields are used to store 3D-CAD drawing details, which include pipe, pipe fittings and other inline items. Figure 16 shows the screen shot of attributes of the 3D-CAD system in SQL database.

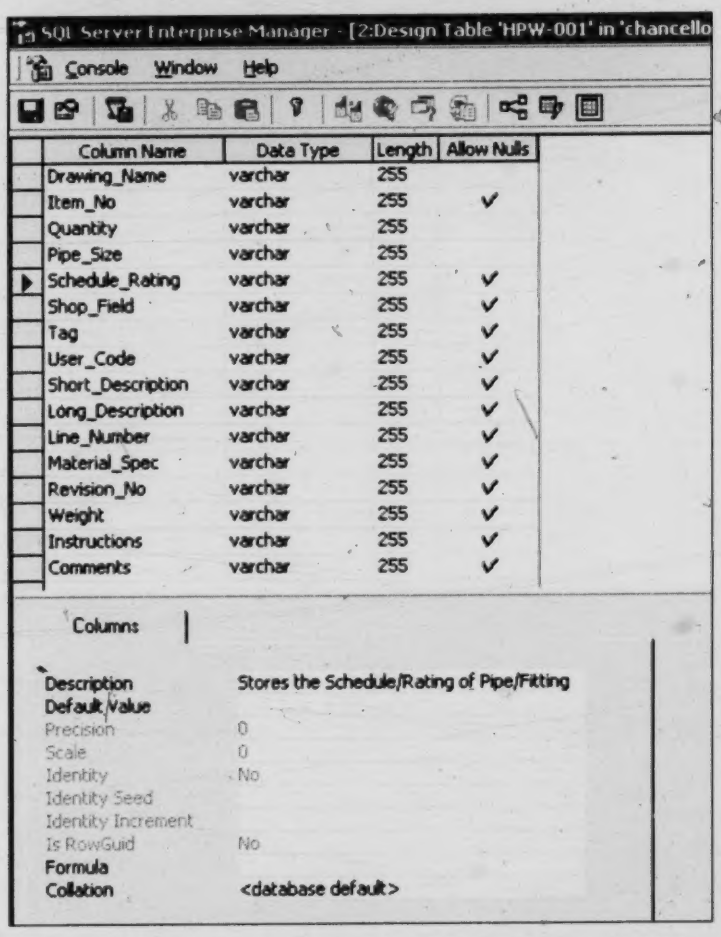
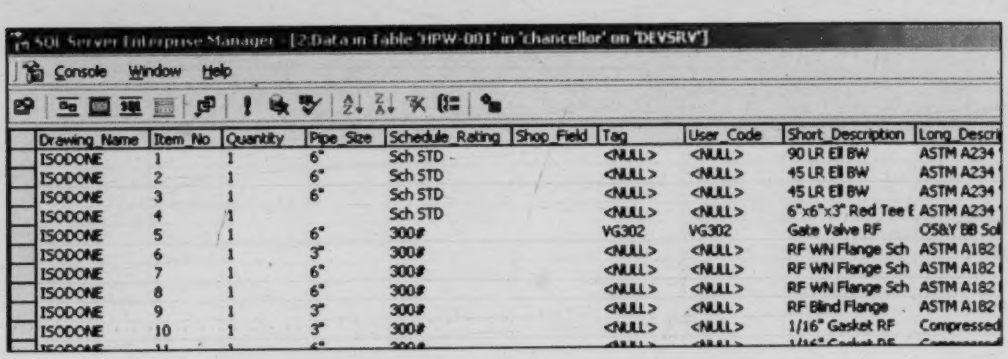


Figure 16: List of Attributes of the 3D-CAD System in SQL

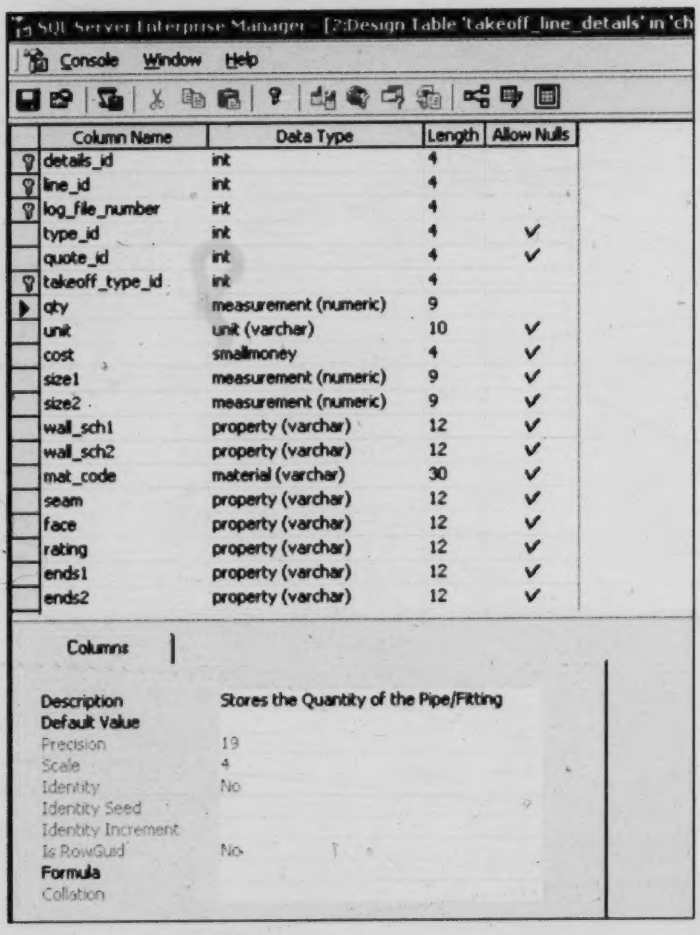


SQL Server Enterprise Manager - [2:Data in Table 'HPW-001' in 'chancellor' on 'DEVSRV']

Console Window Help

Drawing_Name	Item_No	Quantity	Pipe_Size	Schedule_Rating	Shop_Field	Tag	User_Code	Short_Description	Long_Descri
ISODONE	1	1	6"	Sch STD		<NULL>	<NULL>	90 LR Ell BW	ASTM A234
ISODONE	2	1	6"	Sch STD		<NULL>	<NULL>	45 LR Ell BW	ASTM A234
ISODONE	3	1	6"	Sch STD		<NULL>	<NULL>	45 LR Ell BW	ASTM A234
ISODONE	4	1		Sch STD		<NULL>	<NULL>	6"x6"x3" Red Tee E	ASTM A234
ISODONE	5	1	6"	300#		VG302	VG302	Gate Valve RF	OS&Y BB Sol
ISODONE	6	1	3"	300#		<NULL>	<NULL>	RF WN Flange Sch	ASTM A182
ISODONE	7	1	6"	300#		<NULL>	<NULL>	RF WN Flange Sch	ASTM A182
ISODONE	8	1	6"	300#		<NULL>	<NULL>	RF WN Flange Sch	ASTM A182
ISODONE	9	1	3"	300#		<NULL>	<NULL>	RF Blind Flange	ASTM A182
ISODONE	10	1	3"	300#		<NULL>	<NULL>	1/16" Gasket RF	Compressed

Figure 17: Sample Instances of the 3D-CAD system in SQL



SQL Server Enterprise Manager - [2:Design Table 'takeoff_line_details' in 'ch

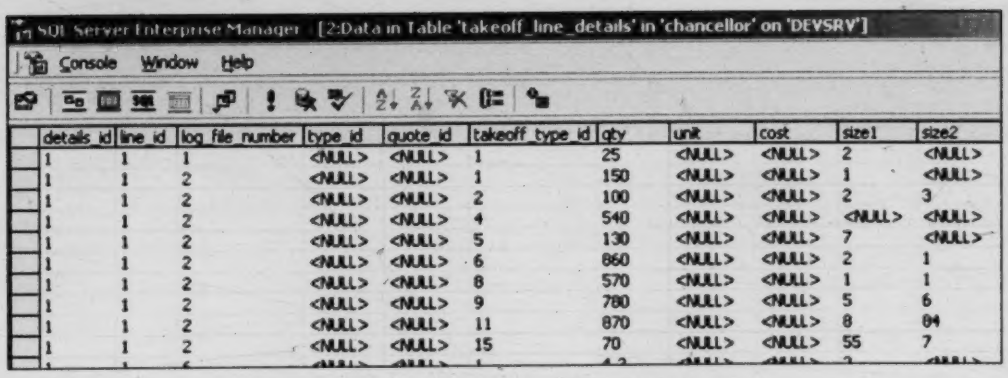
Console Window Help

Column Name	Data Type	Length	Allow Nulls
details_id	int	4	
line_id	int	4	
log_file_number	int	4	
type_id	int	4	✓
quote_id	int	4	✓
takeoff_type_id	int	4	
qty	measurement (numeric)	9	
unit	unit (varchar)	10	✓
cost	smallmoney	4	✓
size1	measurement (numeric)	9	✓
size2	measurement (numeric)	9	✓
wall_sch1	property (varchar)	12	✓
wall_sch2	property (varchar)	12	✓
mat_code	material (varchar)	30	✓
seam	property (varchar)	12	✓
face	property (varchar)	12	✓
rating	property (varchar)	12	✓
ends1	property (varchar)	12	✓
ends2	property (varchar)	12	✓

Columns

Description	Stores the Quantity of the Pipe/Fitting
Default Value	
Precision	19
Scale	4
Identity	No
Identity Seed	
Identity Increment	
Is RowGuid	No
Formula	
Collation	

Figure 18: List of Attributes of the IMS in SQL


SQL Server Enterprise Manager - [2:Data in Table 'takeoff_line_details' in 'chancellor' on 'DEVSRV']

Console Window Help

details_id	line_id	log_file_number	type_id	quote_id	takeoff_type_id	qty	unit	cost	size1	size2
1	1	1	<NULL>	<NULL>	1	25	<NULL>	<NULL>	2	<NULL>
1	1	2	<NULL>	<NULL>	1	150	<NULL>	<NULL>	1	<NULL>
1	1	2	<NULL>	<NULL>	2	100	<NULL>	<NULL>	2	3
1	1	2	<NULL>	<NULL>	4	540	<NULL>	<NULL>	<NULL>	<NULL>
1	1	2	<NULL>	<NULL>	5	130	<NULL>	<NULL>	7	<NULL>
1	1	2	<NULL>	<NULL>	6	860	<NULL>	<NULL>	2	1
1	1	2	<NULL>	<NULL>	8	570	<NULL>	<NULL>	1	1
1	1	2	<NULL>	<NULL>	9	780	<NULL>	<NULL>	5	6
1	1	2	<NULL>	<NULL>	11	870	<NULL>	<NULL>	8	84
1	1	2	<NULL>	<NULL>	15	70	<NULL>	<NULL>	55	7

Figure 19: Sample Instances of the IMS in SQL

Figure 17 shows the screen shot of the sample of instances of the 3D-CAD system in SQL. Figure 18 shows the screen shot of the list of attributes of the information management system in SQL. Figure 19 shows the sample instances of the information management system in SQL. The default data type for the 3D-CAD system is "varchar" and its length is 255 characters. The 3D-CAD data is stored as table "HPW-001" in the SQL database. This table of quantity take-off data is mapped with the information management system database. The target table in the information management system is "takeoff_line_details". This table has twenty-six attributes as shown in Figure 18. The data types of the attributes are different than that of the 3D-CAD table. This mismatch of data types is scrubbed and normalized before processing as explained in the system implementation section.

4.3 System Implementation

System implementation was carried out in three steps. Since this project was in the piping industry, piping software CADPIPE 2004 was used to model the piping system. 3D and ISO modules of the CADPIPE 2004 software are used to implement the system. CADPIPE 3D Design is a three dimensional software program that uses the conventional AutoCAD environment to allow piping drawing in any direction. This can be done without changing

user coordinate systems or projection planes, while automatically checking for interference problems. CADPIPE ISO is fully integrated module of the CADPIPE 2004 software. This module can create system isometrics (ISO) or spool drawings automatically from 3D module drawings. The drawings can be edited and modified using the editing tools available in this module.

Table 2: Bill of Material for the Piping System Case Study

Bill of Material as per the plan drawing					
Item	**Quantity**	**Size**	**Code**	**Rating**	**Description**
1	1	6"		Sch STD	90 Degree LR Elbow ASTM A234 WP11
2	2	6"		Sch STD	45 Degree LR Elbow ASTM A234 WP11
3	1			Sch STD	6"X6"X3" Reducing Tee ASTM A234 WP11
4	1	6"	VG302	300#	Gate Valve RF, ASTM A217 WC6
5	1	3"		300#	RF WN Flange Sch STD ASTM A182 F11
6	2	6"		300#	RF WN Flange Sch STD ASTM A182 F11
7	1	3"		300#	RF Blind Flange ASTM A182 F11
8	1	3"		300#	1/16" Gasket RF Compressed
9	3	6"		300#	1/16" Gasket RF Compressed
10	32'	6"		Sch STD	Pipe Smls ASTM A335 P11
11	8	3/4"			Stud Bolt 4 1/4" A193 B7
12	36	3/4"			Stud Bolt 4 3/4" A193 B7

The case study selected for system implementation is a 6" seamless pipe, joining a vessel with a pump. The pipe run has a 6" gate valve with other fittings along the run. The bill of material (BOM) for the case study is shown in Table 2. Following steps explain the system implementation process.

4.3.1 Step 1: The 3D Model

The system implementation began in the design phase of the project, where the piping designer collects project information and uses historical data and experience to model the

project. Project information includes piping and instrumentation drawings (P&ID) and plan drawings, which are used to design a piping system in 3D-CAD environment. Built into CADPIPE 3D Design software are pull-down menus and toolbars. Before actually starting to draw a pipe, it is important to set the specification options in CADPIPE 3D Design. The specification option is selected from "3D Design" menu and the 3D Design Specification Options dialog box is shown in Figure 20. The description of some of the available options is as follows:

Line Number: This field sets the line number that will apply to piping run and fittings. This information is listed with the pipe or fitting in a report.

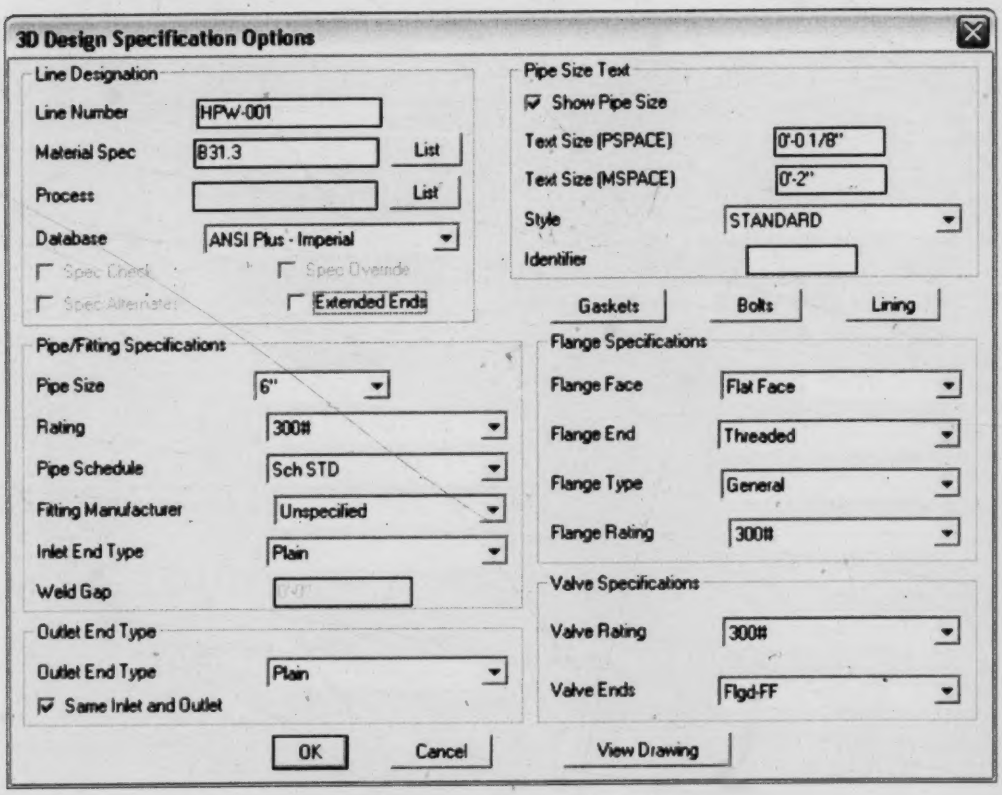


Figure 20: The 3D Design Specification Options Dialog Box

Material spec: This field associates a material specification with the fitting or pipe in a drawing. The specification is listed with the pipe or fitting in a report. Customized specifications can also be generated using CADPIPE specification generation program.

Process: This field associates a process with the fitting or pipe in a drawing. The process does not appear on the drawing unless line designation text is placed with the query command.

Database: This field allows user to select a fitting database for the drawing session. Wide selection of international databases includes: ANSI plus, DIN, British standards, AFNOR and JIS. These databases can also be customized to suit the needs. As the case study follows ANSI standard the ANSI Plus – Imperial database is selected.

Spec Check/Spec Override: The specification chosen in this material spec field will apply to all settings in the dialogue box. If the pipe size is changed during the course of drawing, other fitting and flange specifications are updated according to the material spec.

Fittings Specifications: This section allows user to change the pipe size, rating, schedule, and end type settings.

Flange/Valve Specifications: In this section various parameters of flange and valve can be set. If spec check is on these parameters are automatically set.

All pipes and fittings get their dimensions either from the material specifications or the settings user enters in the 3D specifications options dialog box. This provides the user total control over how each fitting is represented on the drawing. Next, to start drawing "start a run" command is selected from the 3DDESIGN menu or the design toolbar. This prompts for line number, starting elevation, join and angle up/down options. The angle up/down option refers to the AutoCAD horizontal drawing angle or the direction in which the user

want to draw the pipe run. After entering the elevation, location, and direction, the system places the pipe and fitting picked from the menu. The next fitting is automatically joined to the first or existing fitting, and the parameters are automatically matched. The options dialog box allows user to change settings that control placement of pipe and fittings. It can be selected from 3DDESIGN menu. Figure 21 shows the 3D Design Options dialog box. Some of the available options are explained below.

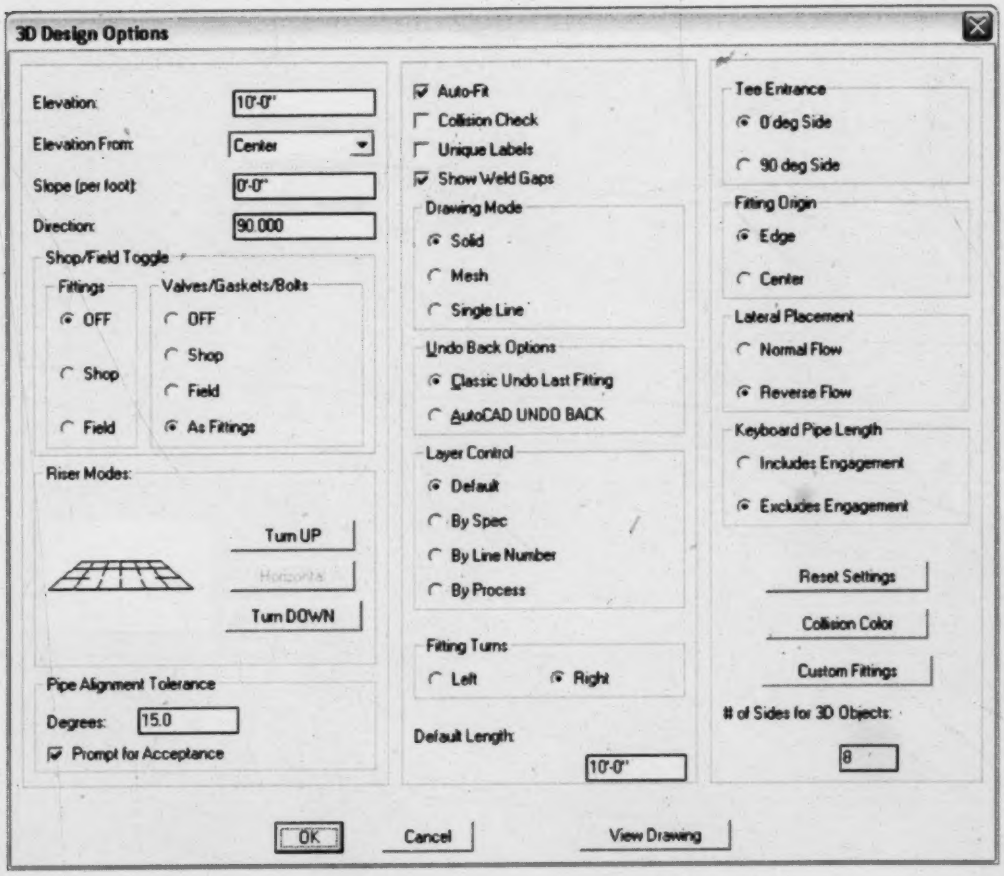


Figure 21: 3D Design Options Dialog Box

Elevation: This box displays the elevation for the pipe or fitting to be drawn. This elevation value is automatically updated as the pipe is drawn at various elevations.

Elevation from: This box sets the point from which the elevation is set. The elevation can be measured from the center, top or bottom of a fitting or pipe run.

Slope: This box displays the slope of the pipe and fittings to be drawn. Slope can be entered in inches per foot, as a percentage or as a ratio.

Direction: The value entered in this box is the direction or angle at which the pipe or fitting will be drawn. This direction angle is automatically updated as the pipe run makes turns.

Collision checking: This toggle controls the Interactive Collision Checking feature. It alerts user to collisions between the current run and any 3D object on the drawing.

Collision color: User can select a color to be used when a collision is found. The colliding objects are highlighted with this color.

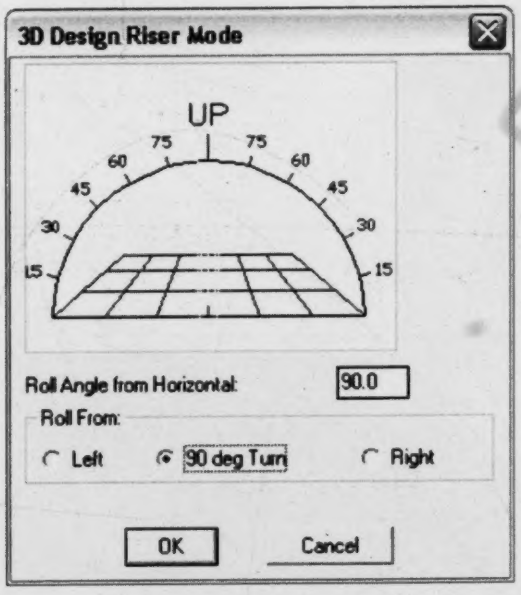


Figure 22: 3D Design Riser Mode Dialog Box

Turn up/down: As the user selects "Turn UP" or "Turn Down" button from the 3D Design Options dialog box, "3D Design Riser Mode" dialog box appears as shown in the Figure 22. This dialog box can be used to set the roll angle for the fitting as it turns up or down. This angle can be any angle from 0 to 90 degrees rolling to the left, or 0 to 90 degrees rolling to the right. The system continues to draw at the roll angle in an up or down direction until the user selects another fitting that will return to plan or horizontal.

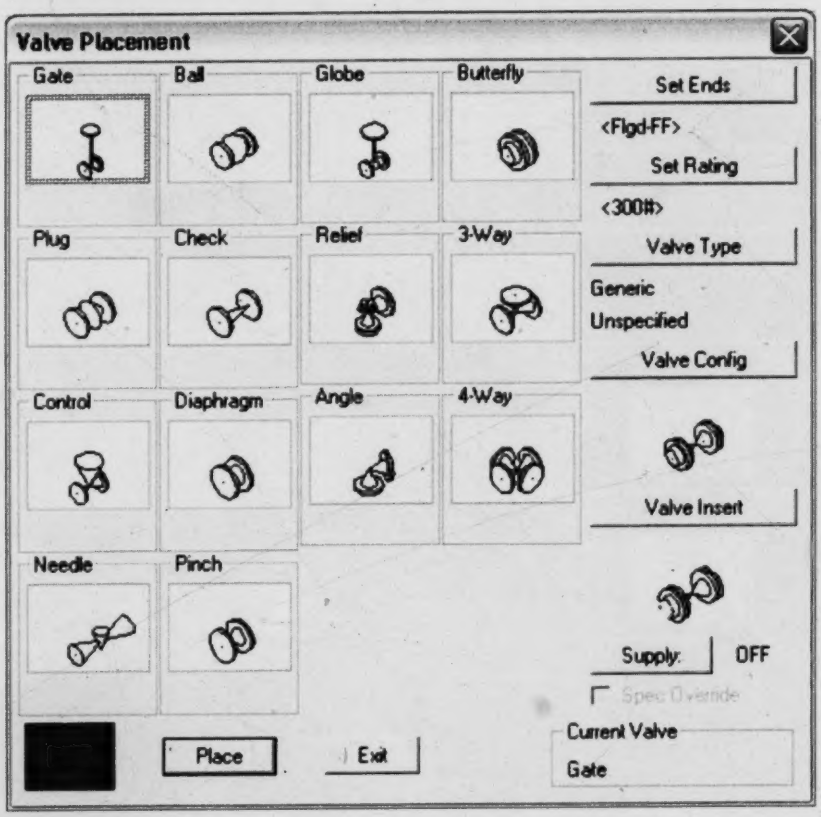


Figure 23: Valve Placement Dialog Box

As the case example has a valve in pipe run, the option "Valve" is selected from the fittings menu to place a valve on the drawing. Figure 23 shows the 3D Design Valves dialog box.

The dialogue box shows all the various types of valves available. As per specifications, a 6", 300# Gate valve is placed on the pipe run.

The pipe run has a pump at the other end; hence the option of "Pump" is selected from the Equipment menu. Figure 24 shows the various types of pumps available. A centrifugal pump is selected and in the following dialog box suction/discharge details along with base plate and location details are provided. All dimensions are referenced from the bottom of base plate elevation (BP).

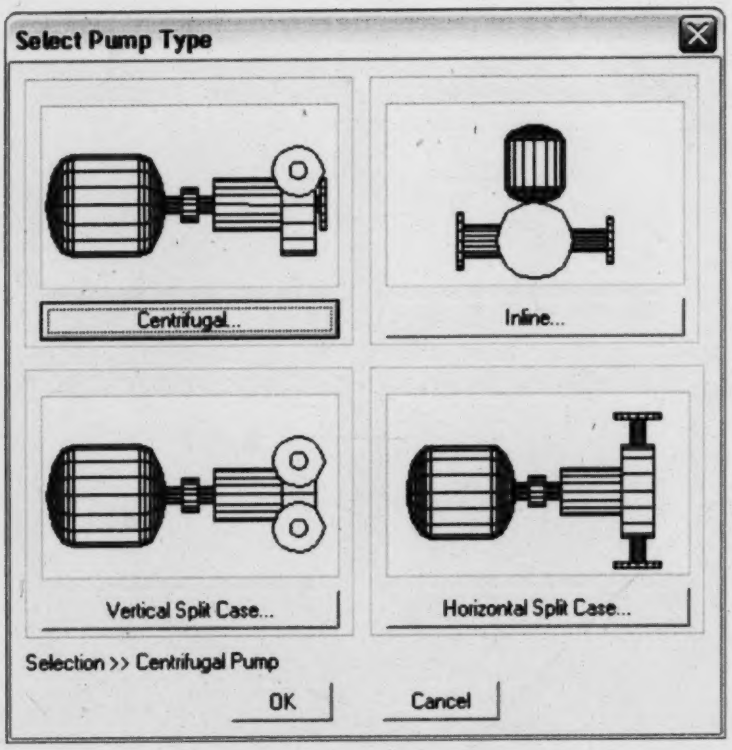


Figure 24: Select Pump Type Dialog Box

To create and place a vessel on the 3D model, option "Vessel" is picked from the Equipment menu. Figure 25 shows the Vessel Information Dialog box. The option of vertical vessel orientation is selected. Then elevation, end types, diameter and tan-to-tan

length is entered. Nozzle location and orientation is finalized from the following dialog box. This creates the basic shape of a vessel with a nozzle attached to it.

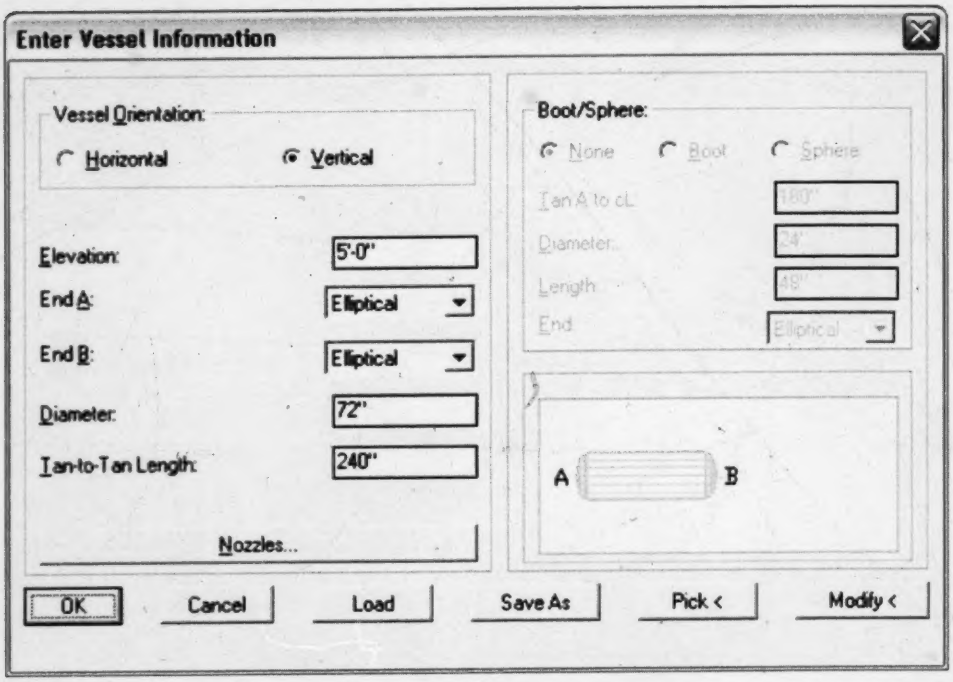


Figure 25: Enter Vessel Information Dialog Box

The next step is to create some structural members to complete the 3D drawing of the piping system. To draw the structural members in 3D-CAD environment, the option "Column" from the Structural menu is selected. A prompt "Point for Column" appears. This point is the center point for the column. In the "Intersection Snap" mode, intersections for column placement are selected. After the point is selected for column, a dialog box appears as shown in the Figure 26.

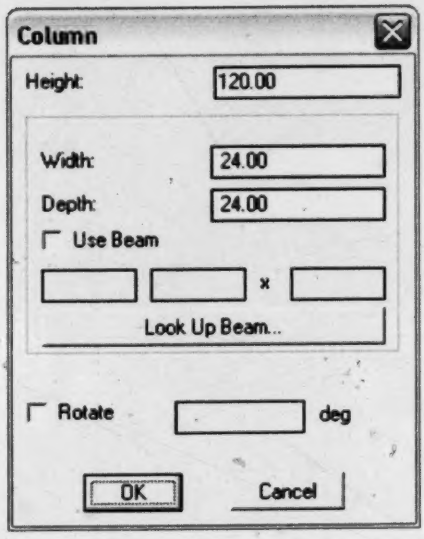


Figure 26: Column Details Dialog Box

In this dialog box, the height, width and depth of the column are specified. To select the type of column "Look up Beam" is selected, which shows a dialog box with various shapes of beams as shown in Figure 27.

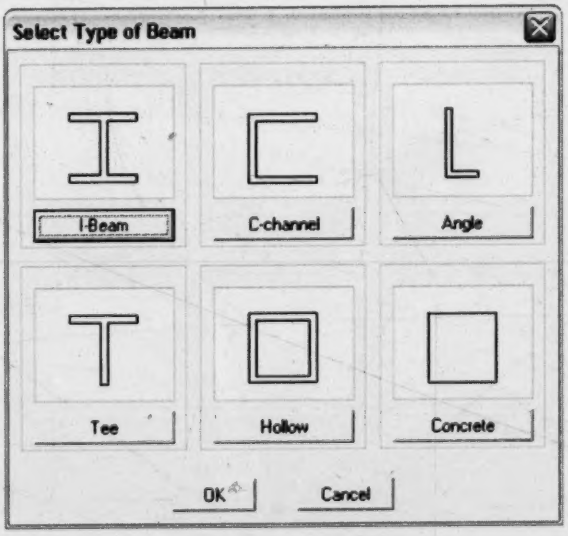


Figure 27: Select Beam Type Dialog Box

The column database shares its database with the beams database. A beam can also be utilized as a column by clicking the "Use Beam" check box. Four columns and ten beams are placed as per requirement to complete the 3D model of the piping system. The completed 3D model of the case study is shown in Figure 28.

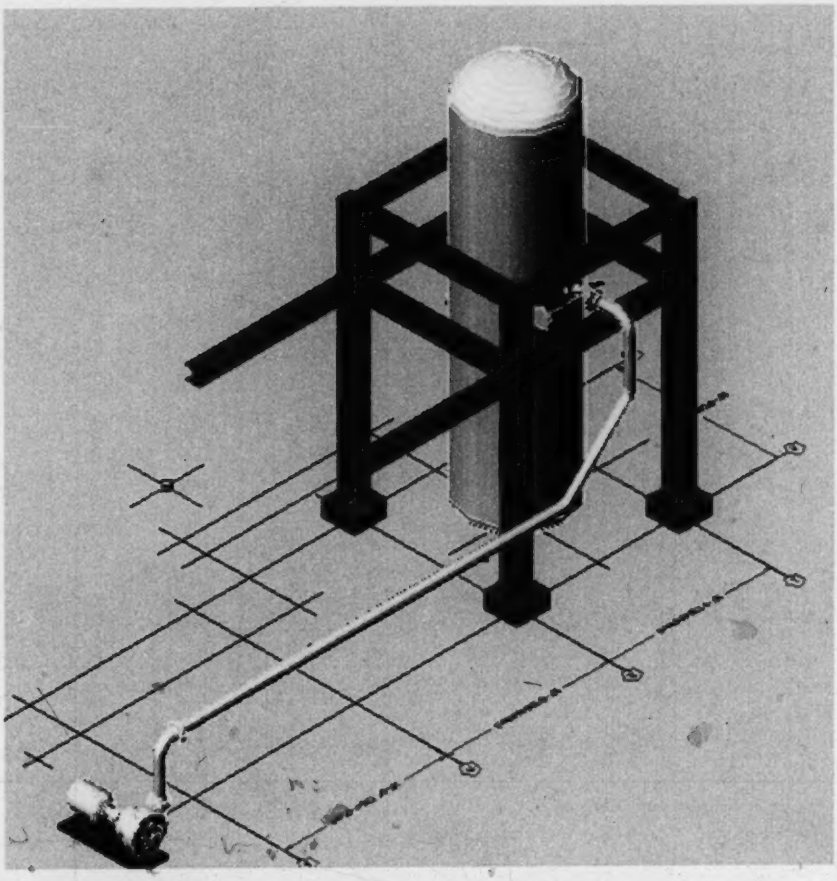


Figure 28: Front Loaded 3D Design of the Pipeline

Front loading of data enables the normal 3D-CAD piping drawings to transform to a repository of information, which is useful in the construction and estimation phase of the

project. The completion of the 3D-CAD drawing completes the first step of the implementation process. The second step deals with the ISO module of the system.

4.3.2 Step 2: The ISO Model

In the second step of the implementation process, designer verifies the 3D design data and checks the accuracy of the drawings. After establishing the design and other data the designer then exports the universal data exchange (UDE) file to the isometric (ISO) module. To export the data from 3D module option "UDE Out" from utilities menu is used. Figure 29 Shows the UDE Out dialog box. Here, the network location and items to be exported are specified. The universal data exchange file contains the front loaded data along with the design data.

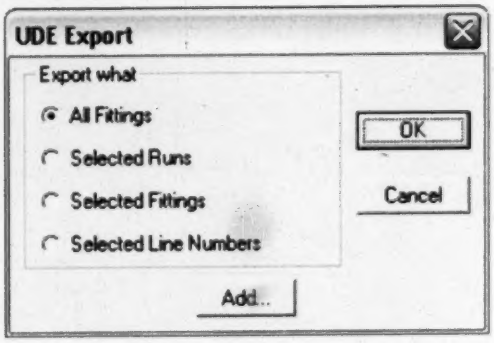


Figure 29: The UDE Export Dialogue Box

3D module of the information management system is exited after the UDE file is exported to a network location. Next, the ISO module of the CADPIPE 2004 software is opened; the option of "Prepare Prototype" is selected from the auto menu. Drawing "isometric" is selected from the dialog box. This drawing is an empty isometric drawing prototype. The drawing layout area is selected after the prompt. After the drawing layout is specified,

option "iso" is selected from the auto menu. The dialog box prompts for network location of the UDE file as shown in Figure 30.

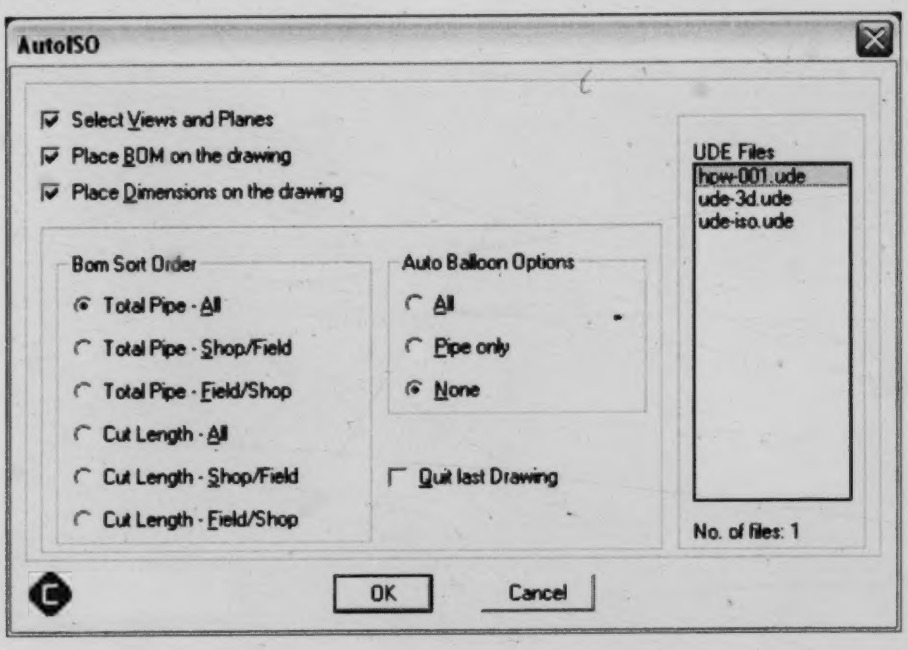


Figure 30: The Auto ISO Dialogue Box

As the network location of the UDE file is specified, the UDE file form the 3D module is imported to the ISO module. This framework allows changing the traditional method of information sharing by using generic design data files for construction. This electronic data transfer between the modules avoids duplication of work by designers and other team players. The orientation and scale of the drawing is set in the prompt. The Isometric drawing is automatically generated with all fittings and dimensions in the prototype drawing.

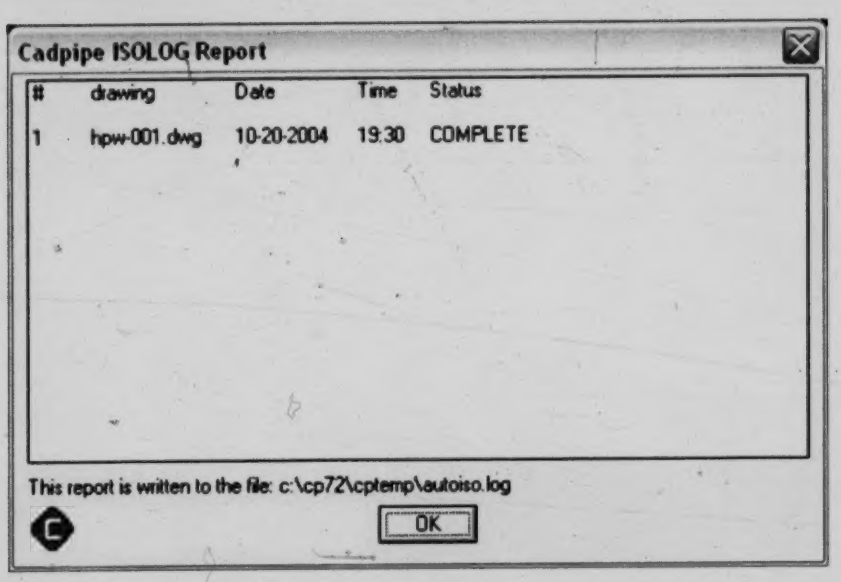

Cadpipe ISOLOG Report
drawing Date Time Status
1 hpw-001.dwg 10-20-2004 19:30 COMPLETE
This report is written to the file: c:\cp72\cptemp\autoiso.log
OK

Figure 31: The Cadpipe ISOLOG Report

Figure 31 shows the Cadpipe ISOLOG report, which is generated after the successful import of the UDE file in ISO module and automatic generation of the isometric drawing. This dialogue box displays the number, name, date, time and status of drawing. It also displays the path of the log report that has been written to a work folder. Figure 32 shows the automatically generated isometric drawing in the ISO module. Bill of quantity is automatically generated and placed on top of the isometric drawing. The isometric drawing can be modified to suit the site conditions and a shop or field isometric can be generated. The isometric drawing is checked and the UDE file is exported from ISO module to a network location. To export UDE file, the option of "UDE Out" is selected from the utilities menu. The network location is specified and the UDE file is exported to a network location.

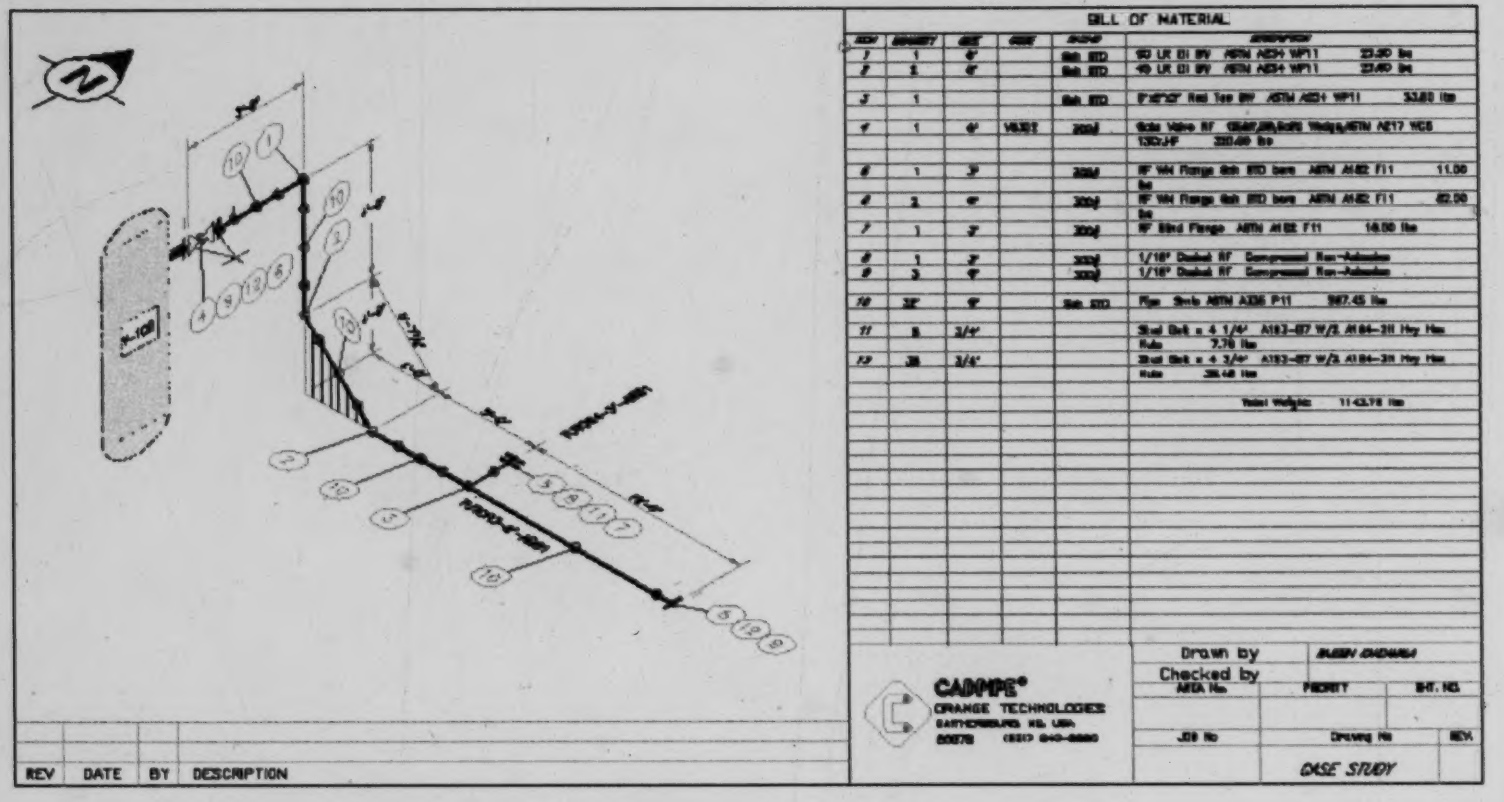


Figure 32: Automatic ISOMETRIC Drawing generated by UDE file

4.3.3 Step 3: Data Export to Information Management System

The third and last step of system implementation involves exporting the quantity take-off data to the information management system database. The take-off data is analyzed for accuracy and completeness before exporting. The data is scrubbed and normalized to make it compatible with the data structure of the information management system. Information management system has a different data structure than that of the isometric module's data structure. As explained in the previous section, the isometric module has sixteen attributes whereas information management system has twenty-six attributes. The data type of the isometric module is "varchar" by default whereas the information management system has various types of data types for its twenty-six attributes. Scrubbing ensures that noisy data can be eliminated. Data transformation system is used to carry out scrubbing of data. Data mapping ensures compatibility of data with target database by changing the data types. To incorporate these features, option of enterprise manager is selected in the SQL server. The information management server is started from the SQL Server Group to open the databases list.

A data transformation package is created to import take-off data from the 3D-CAD module. To design a DTS package in SQL database the source and destination package has to be identified. Figure 33 shows the DTS package design in SQL environment. This DTS package has the UDE file in ".csv" format as the source file. In this package "takeoff_line_details" table is selected as the destination in the information management system. Next, the transformation package design process starts as explained hereunder. The left panel of the DTS package designer window consists of "Connection" and "Task" toolbars. These toolbars are used to design the DTS package.

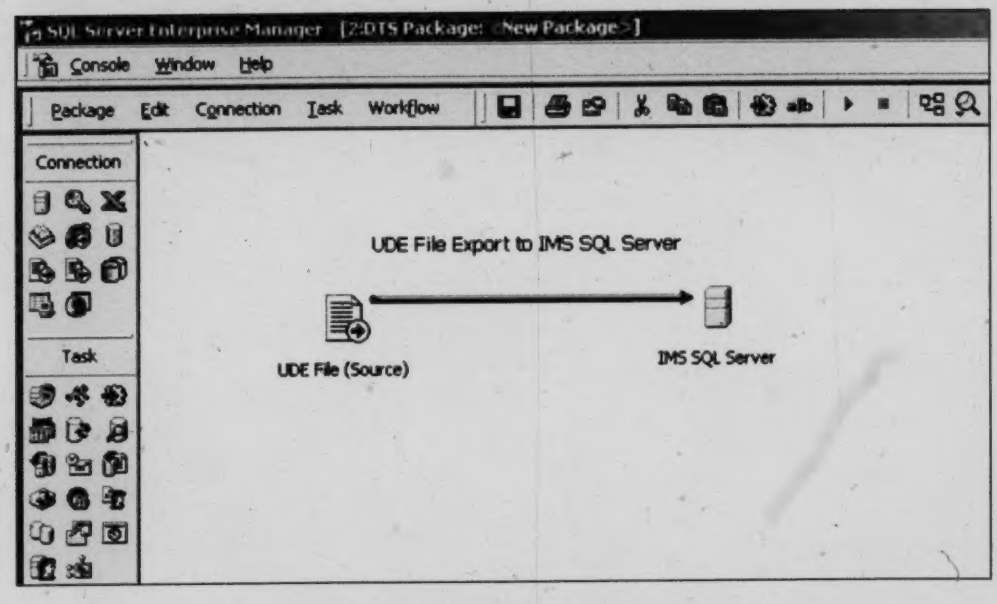


Figure 33: DTS Package design in SQL

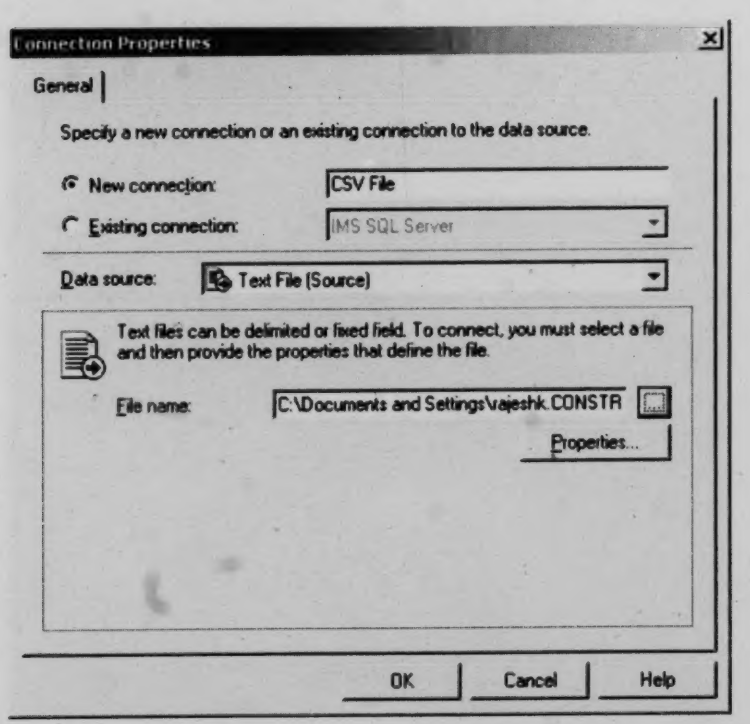


Figure 34: The Source Dialogue Box

The "connection" toolbar displays all possible types of sources and destinations that can be connected through DTS. These include text file, csv file, Microsoft excel file, Access database file etc. A text file is selected from the "connection" toolbar as the source file. Figure 34 shows the source file dialogue box which opens after the text file is selected. This dialogue box has the option of specifying a new connection or an existing connection can be reused. The data source is selected as the text file and the path of the text file is entered. After the text file path is specified its properties are set by clicking the properties button.

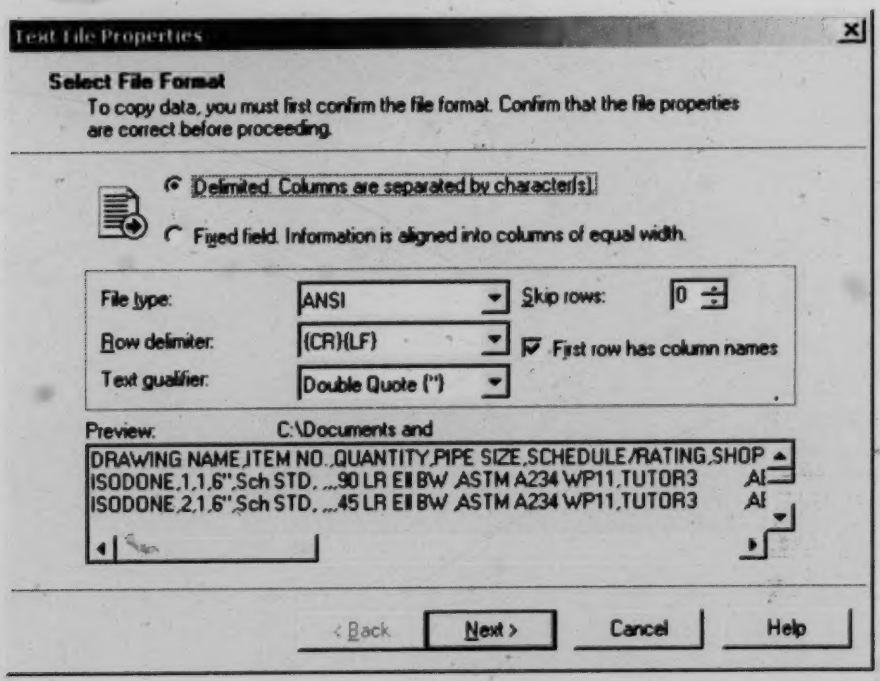

Text File Properties
Select File Format
To copy data, you must first confirm the file format. Confirm that the file properties are correct before proceeding.
Delimited. Columns are separated by character(s).
Fixed field. Information is aligned into columns of equal width.
File type:
ANSI
Skip rows:
0
Row delimiter:
{CR}{LF}
First row has column names
Text qualifier:
Double Quote (")
Preview:
C:\Documents and
DRAWING NAME,ITEM NO.,QUANTITY,PIPE SIZE,SCHEDULE/RATING,SHOP
ISODONE,1,1,6",Sch STD, ...90 LR EII BW ,ASTM A234 WP11,TUTOR3 Al
ISODONE,2,1,6",Sch STD, ...45 LR EII BW ,ASTM A234 WP11,TUTOR3 Al
< Back
Next >
Cancel
Help

Figure 35: The Select File Format Dialogue Box

Figure 35 shows the text file properties dialogue box. File format is confirmed as delimited under the select file format section. File specifications are entered in the following section of the window. Redundant rows can be omitted before transferring it to the information

management system database. A preview of the raw data can be seen in the preview section of the window. The check box "First row has column names" can be selected to automatically design the table with existing column names. By clicking the next button a new window is opened which is shown in Figure 36.

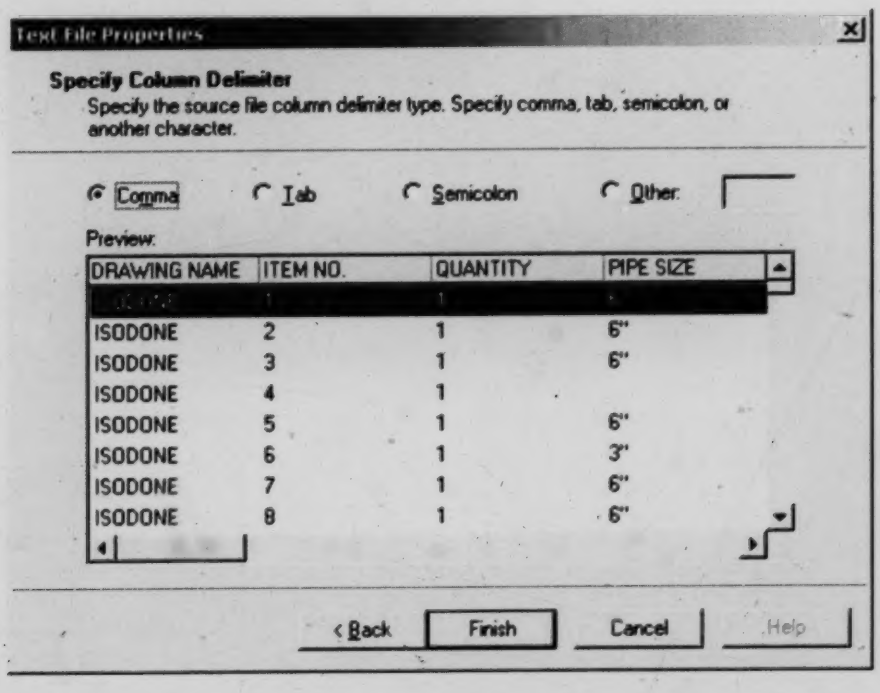


Figure 36: The Specify Column Delimiter Dialogue Box

This dialogue box prompts for specifying column delimiter of the source file. The radio button corresponding to comma is clicked as the text file generated by 3D-CAD has comma as the delimiter. Clicking the option comma displays the take-off data from the source file. First line of the source data shows the name of the columns. Following the first line is the actual take-off data from the 3D-CAD file. This visual display of the take-off data at design stage ensures that the data to be imported in information management system is correct. Finish button is clicked after preview of the take-off data is verified.

The next step in the design of DTS package is to specify the destination of the take-off data. Microsoft SQL server is selected from the connection menu in the design environment. Figure 37 displays the destination dialogue box which is opened after the SQL server is selected form the connection menu.

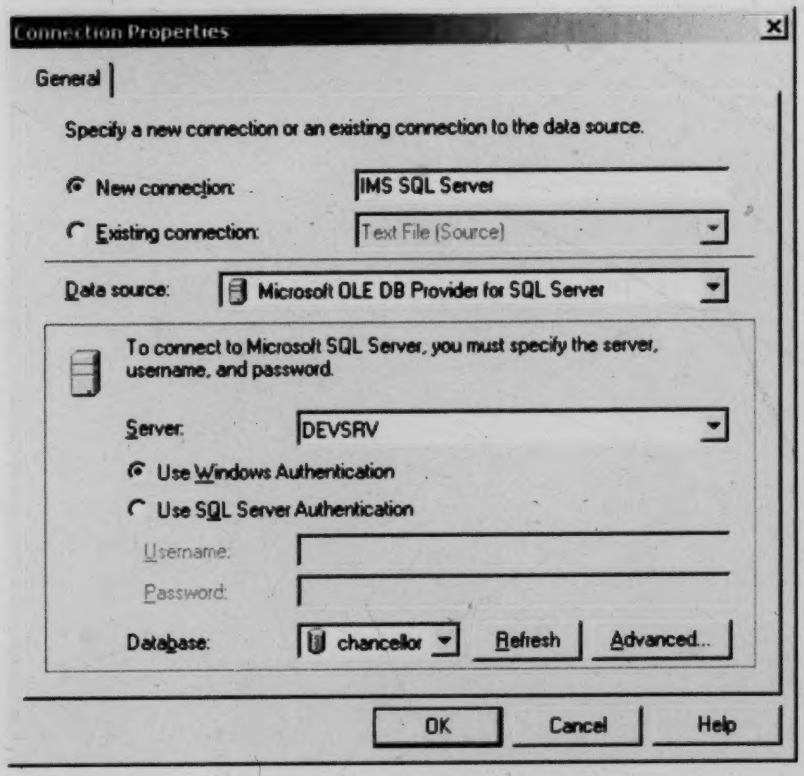


Figure 37: The Destination Dialogue Box

This dialogue box has the option of specifying a new connection or an existing connection can be reused. The option of new connection is selected and the name of the connection is specified as IMS SQL Server. Data source of "Microsoft OLEDB Provider for SQL Server" is selected from the available options of various connections. This prompts for the server and DEVSRV is selected as the information management system database is on this

server. The option of "Use Windows Authentication" is selected. The name of the database in information management system is "chancellor" which is selected in the database field of the dialogue box. This completes the selection of source and destination in the design process.

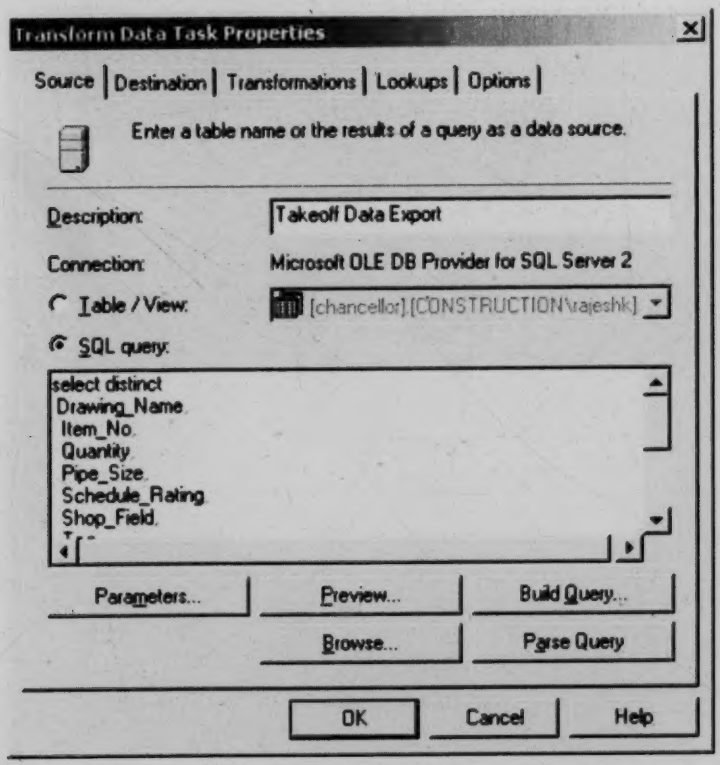


Figure 38: Transform Data Task: Source Tab

The next step in the DTS package design process is to design the task to scrub and map the source data to the destination. Left pane of the design environment has "Task" toolbar for designing this process. "Data Transformation Task" is selected for this purpose from the task bar options and the source file is joined with the destination file using this task. Double clicking this link opens the "Transform Data Task Properties" dialogue box which is used

to design the properties of this task. Figure 38 shows the source tab of the Transform data task properties dialogue box.

This dialogue box shows the source file connection which has been linked with this task and clicking on the preview button shows preview of the take-off data from the source file. The radio button of SQL query allows users to specify queries to filter data. The SQL query can be used to select only the required columns from the source file to be transformed. The columns "Zero Weight Flag" and "Item Code" is filtered out of the import data from the source file. The next tab in the dialogue box displays the destination of the take-off data that has been linked with this task. Figure 39 shows the destination tab of the Transform data task properties dialogue box.

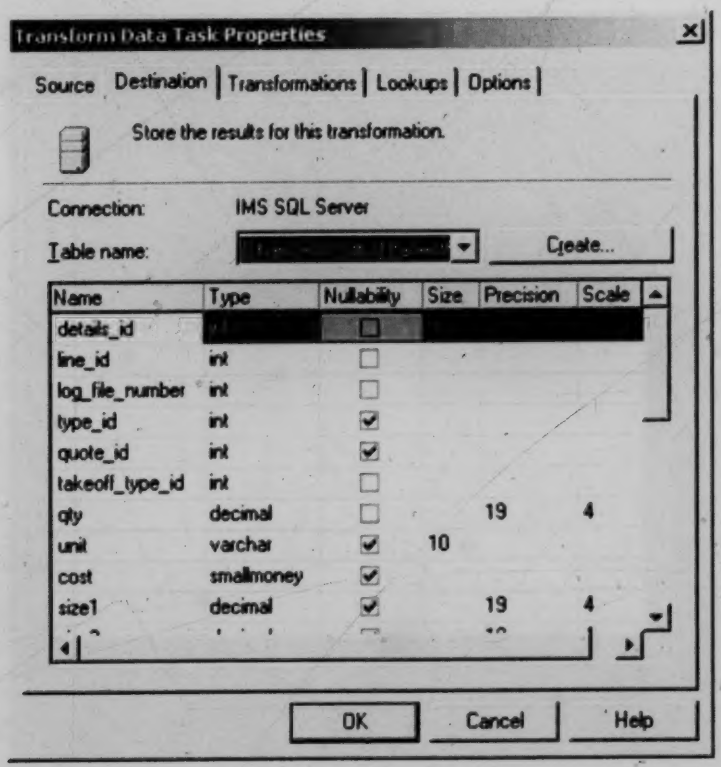


Figure 39: The Transform Data Task: Destination Tab

The combo box "Table name" automatically lists all available tables in the database. A specific table can be selected from the list or a new table can be created in the destination database. The preview section of the dialogue box shows the column names of the selected table along with characteristics of the column. After verifying the data the "Transformations" tab is clicked for designing the scrubbing and normalizing process.

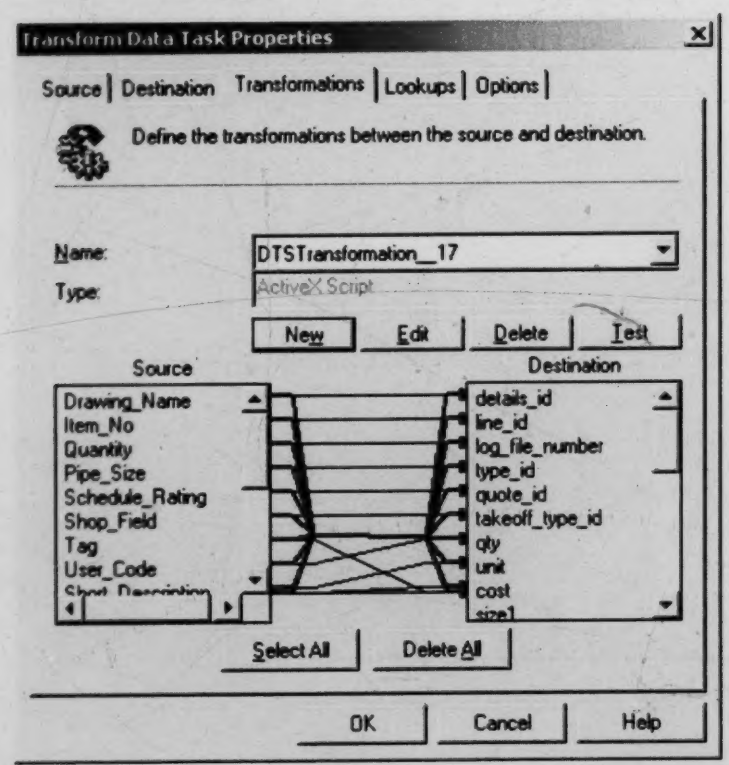


Figure 40: The Transform Data Task: Transformations Tab

Figure 40 shows the transformations tab in the transform data task properties dialogue box. The first step in the transformation process is to define the transformations between the source and destination. This is done by selecting the source and destination columns and then clicking the new button for defining the transformation process. If an existing transformation process is defined it can be selected using the combo box "Name". The

existing transformation definition can be edited using the "Edit" button. Once the "New" button is selected, "Transformation Option" dialogue box is opened.

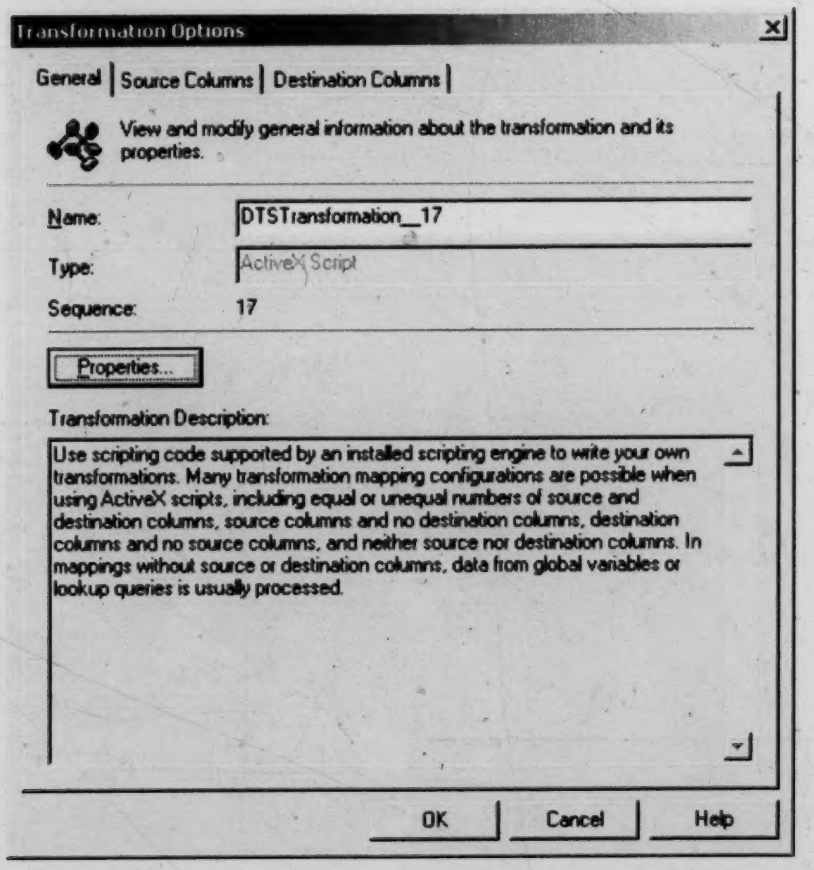

Transformation Options
General
Source Columns
Destination Columns
View and modify general information about the transformation and its properties.
Name:
DTSTransformation__17
Type:
ActiveX Script
Sequence:
17
Properties...
Transformation Description:
Use scripting code supported by an installed scripting engine to write your own transformations. Many transformation mapping configurations are possible when using ActiveX scripts, including equal or unequal numbers of source and destination columns, source columns and no destination columns, destination columns and no source columns, and neither source nor destination columns. In mappings without source or destination columns, data from global variables or lookup queries is usually processed.
OK
Cancel
Help

Figure 41: The Transformation Options: General Tab

Figure 41 shows the transformation options dialogue box and the name of the transformation definition. Properties of the transformation definition can be established by clicking the "Properties" button. As the field "type" indicates ActiveX Script is selected for defining the transformations process. Other types of transformations available are copy column, read file, write file etc. The transformation description section of the dialogue box explains the options of using ActiveX scripts for the transformation definition process.

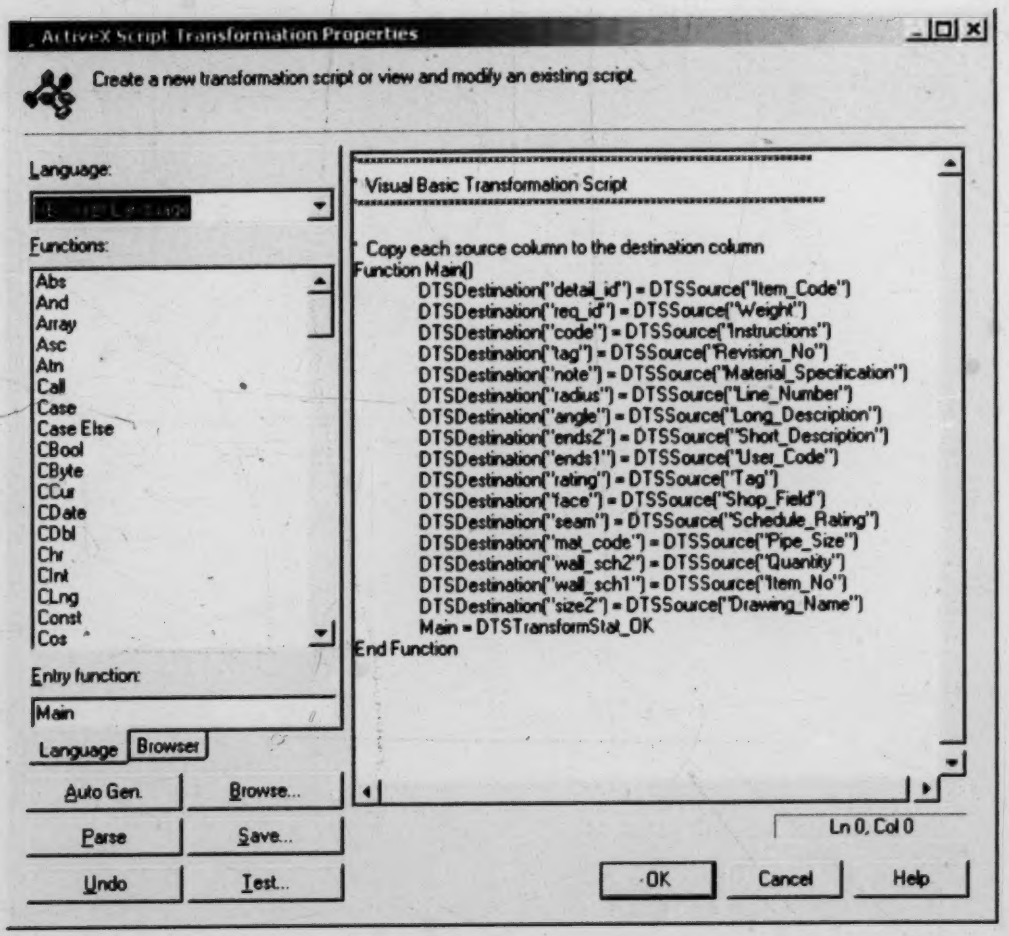


Figure 42: VB Script for Transformation Definition

Figure 42 shows the ActiveX script transformation properties dialogue box. The options for writing the scripting code are displayed in the "Language" combo box. VB script is selected as the scripting language for this package. The other option is Java script. The right panel of the dialogue box shows the visual basic transformation script for scrubbing the take-off data. The scripting code contains a main function for mapping the data between source and destination tables. Auto Gen and other buttons can be used to write the

scripting code for transformations. Each source column is individually mapped to the destination column for take-off data transfer after analysis of the source data. Before the definition process the source and destination columns can be visually selected from the source and destination column tabs. Figure 43 shows the source columns tab.

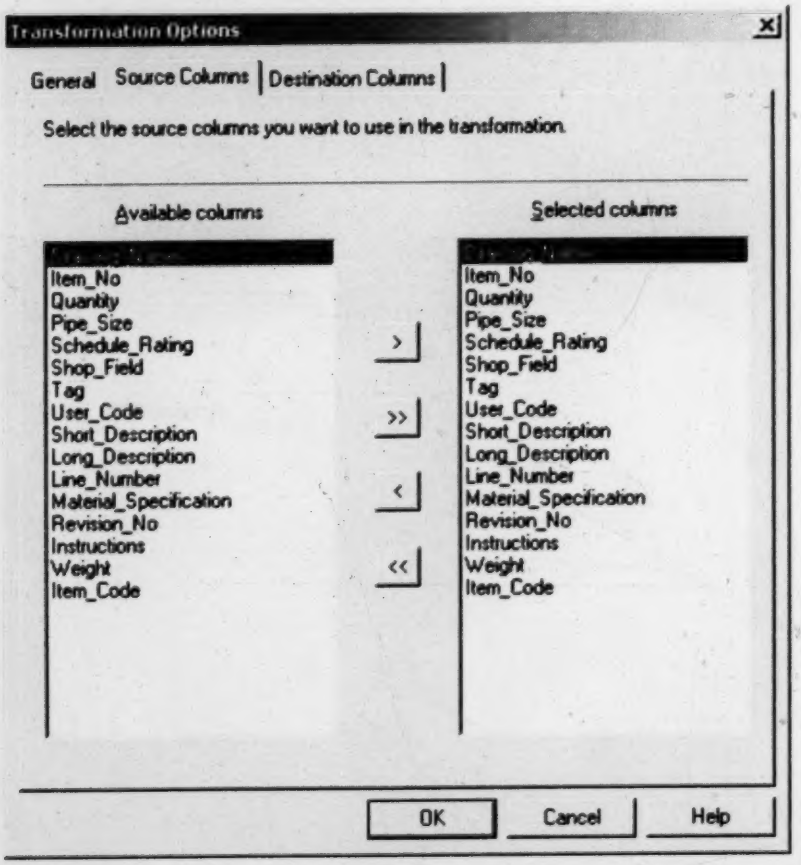


Figure 43: The Transformation Options: Source Columns Tab

The source columns dialogue box enables users to select the source columns to be used in transformation from the available columns. Left panel of the dialogue box lists all the available columns in the source table whereas, the right panel displays the selected column for the transformation process. Columns that don't need transformation can be filtered at

this dialogue box. After all columns are selected for the transformation process from the source table, the destination tab is clicked to design the destination table properties. Figure 44 shows the destination columns tab of the transformation options dialogue box.

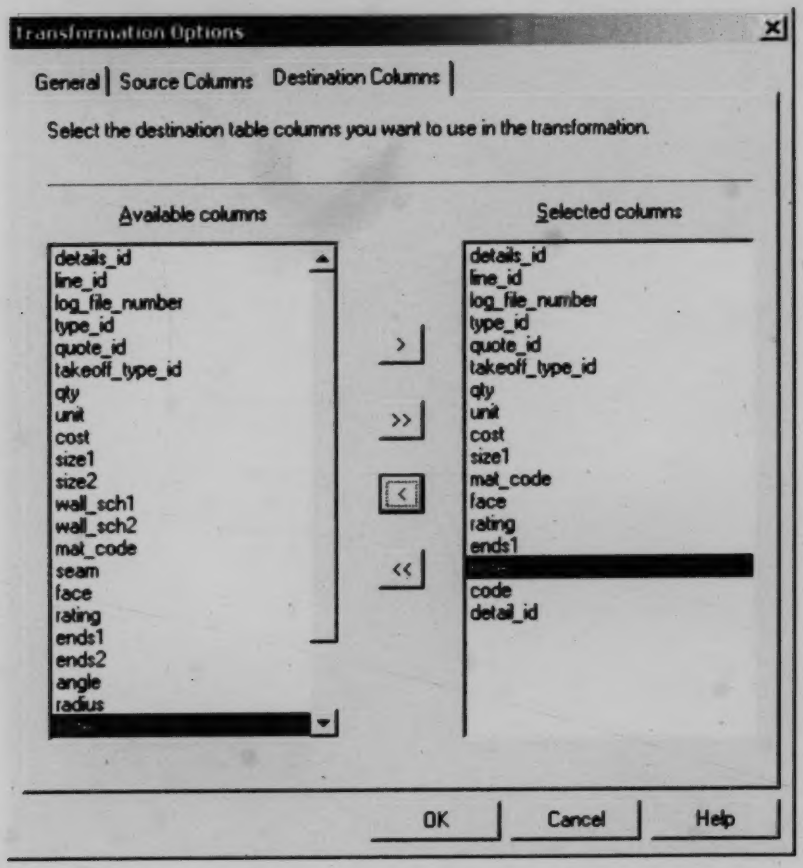


Figure 44: The Transformation Options: Destination Columns Tab

The destination columns dialogue box enables users to select the columns to be transformed from available columns. The columns ends2, wall_sch1, wall_sch2, seam, size2 is removed from the selected columns to be transformed. There is no data from the 3D-CAD system which is saved in the information management system after being

transformed for this DTS package. Once the source and destination columns are identified the ActiveX script for the transformation is ready for execution.

The package is finally checked for any missing links and then it is executed. The ActiveX script transforms the take-off data and stores it in the information management system. Figure 45 shows the result dialogue box after the successful execution of the data transformation package.

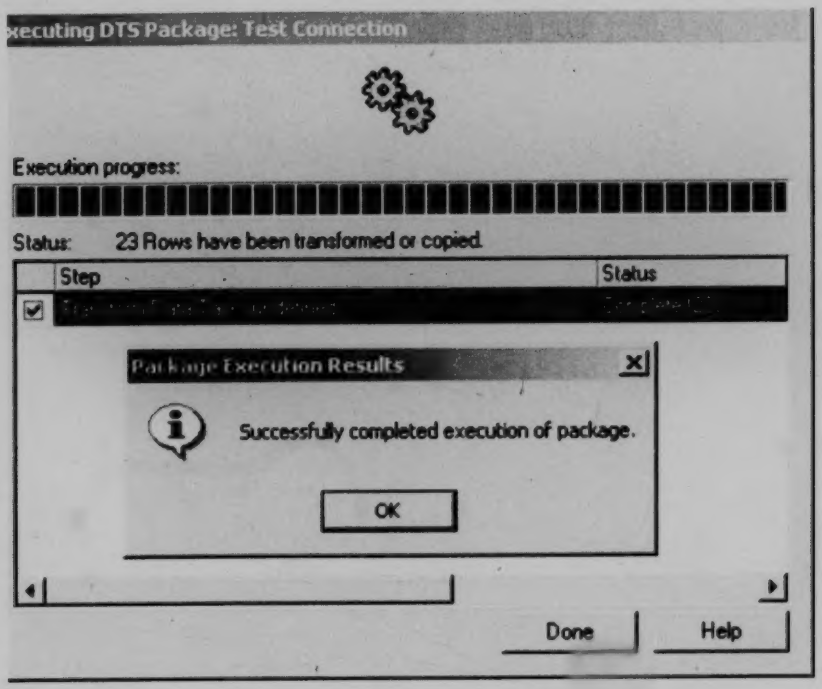


Figure 45: The Result of Package Execution

Figure 46 graphically represents step three of the system implementation process. Data from 3D database and ISO database is modified using the DTS package before being sent to the information management system database. Once the data is stored in the take-off table in the information management system database the system implementation process is completed. The take-off data is processed further by the information management

system. The take-off data is automatically picked-up and displayed in the information management system, which is discussed in the following section.

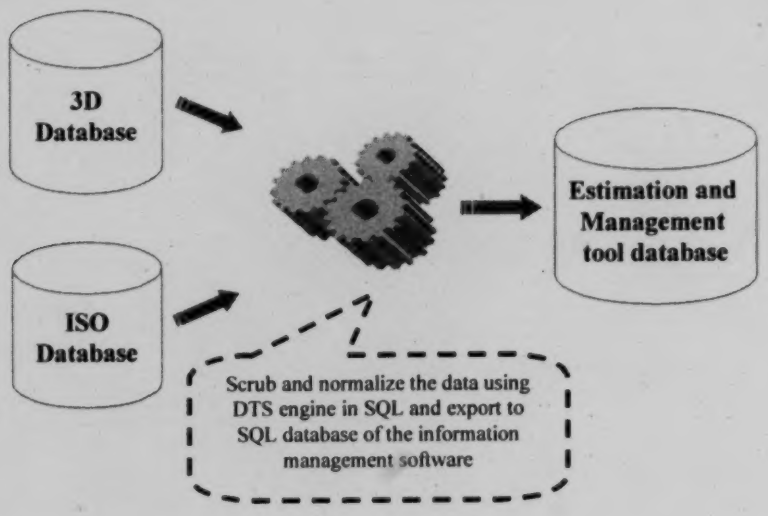

3D Database
ISO Database
Estimation and Management tool database
Scrub and normalize the data using DTS engine in SQL and export to SQL database of the information management software

Figure 46: Data Transformation Process

4.3.4 The Information Management System

In this section the information management system is explained and various features of it are highlighted. As soon as the imported data is stored in the SQL database it is reflected in the estimate inquiry dialog box of the information management system. Basic inquiry detail is entered before the data is used any further. Figure 47 shows the list of all active and inactive enquiries received to date, along with inquiry details and inquiry approvals.

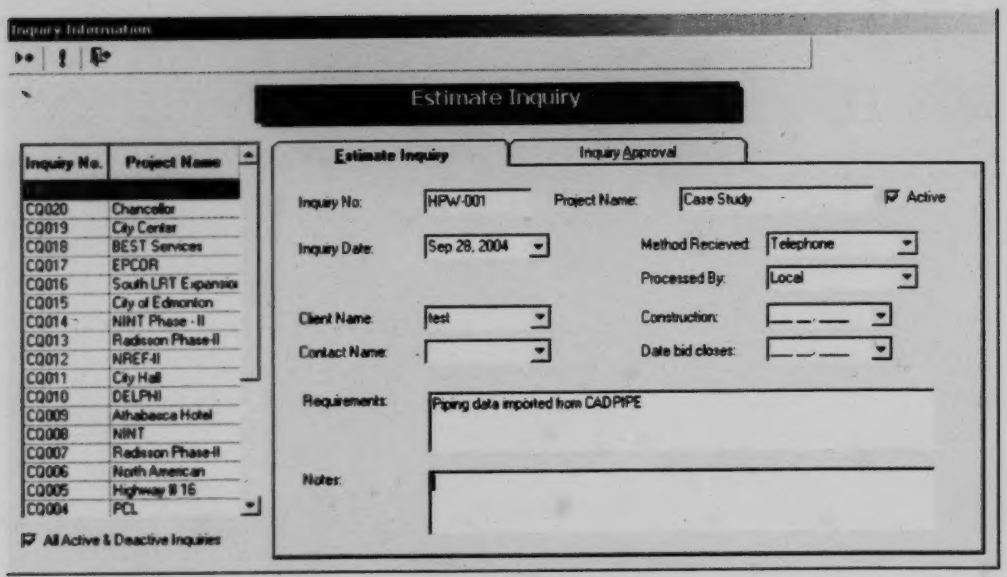


Figure 47: Estimate Inquiry Dialog Box

Details pertaining to the imported data are entered in the dialog box to create a new inquiry for approval. As soon as the manager approves the inquiry, it can be assigned to an estimator for further processing of the data. A "log-file" for the approved inquiry is automatically created by the system, which stores all the project data. Log-file is the central repository system for all modules of information management system.

Once the inquiry is approved, it is activated for further processing. Once the inquiry is selected from the log-file checklist, "Checklist Setup" dialog box is prompted as shown in Figure 48. This checklist setup has three main sections: checklist category, available work descriptions, and selected work descriptions. These three components provide the estimator a quick view of the entire applicable checklist category for the current project, and enables estimator to view the available work descriptions under each checklist

category. As the name suggests, the Checklist category displays all the predefined job categories such as Civil, Equipment, and HVAC.

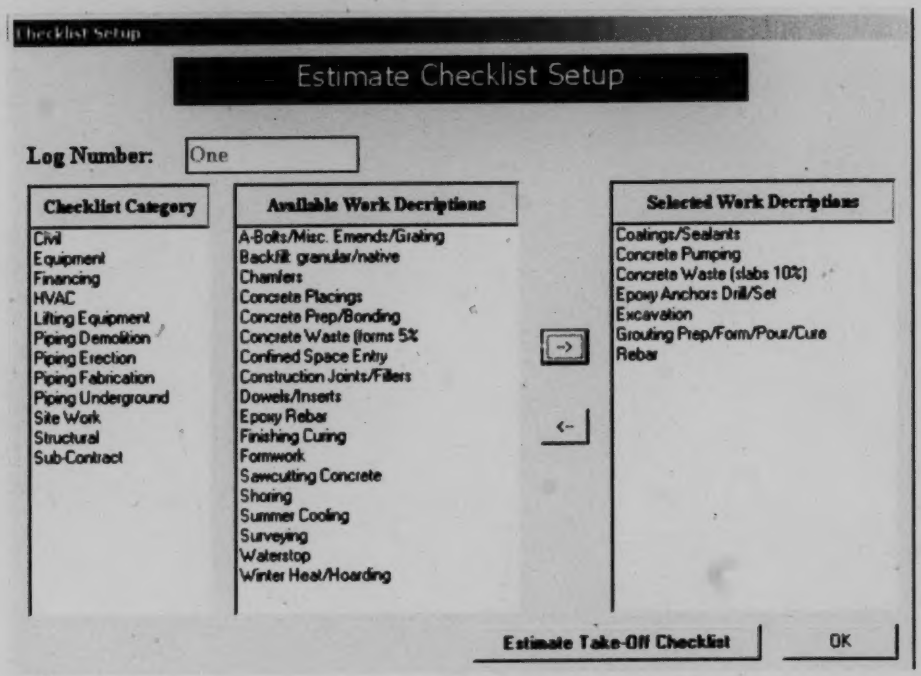


Figure 48: Estimate Checklist Setup Dialog box

The "Available work descriptions" provides the opportunity to browse subcategories for each of the checklist categories and to drag-drop items to the "Selected work descriptions" for the current inquiry. The "Estimate Take-off Checklist" dialog box, shown in Figure 49, has the "Log Number" of the current inquiry and a list of "Checklist categories" that has been selected. As each "Checklist category" is selected, the subcategories corresponding to these categories are displayed in a tabular format. Each subcategory requires Labour, Material, Equipment and/or Sub. Based on the nature of the job and the company policy, suitable checkboxes are selected and the latest version is specified in the Pre-Takeoff dialog box.

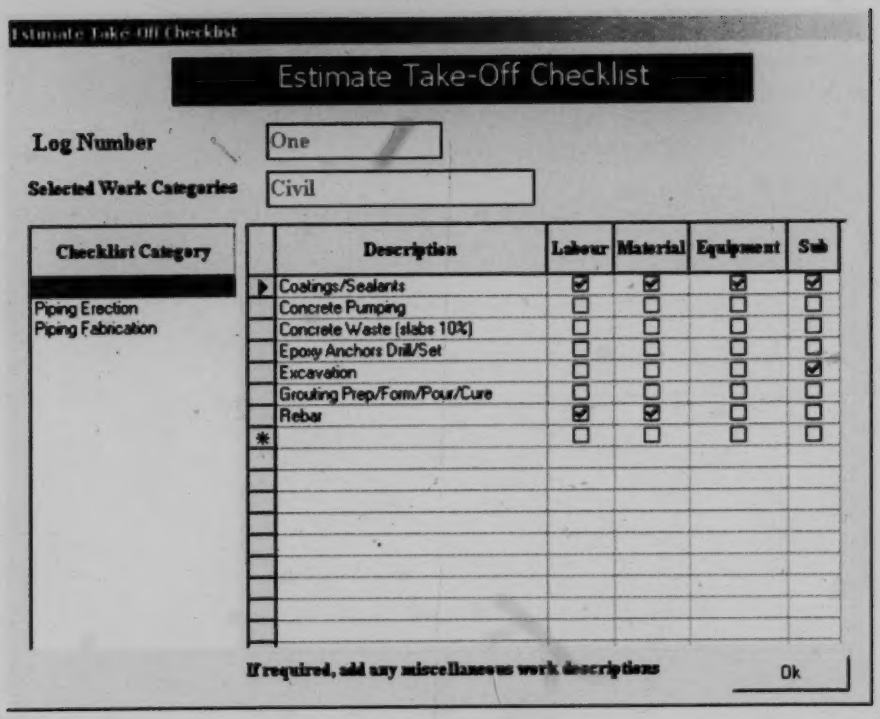


Figure 49: Estimate Take-off Checklist

Once the checklist is completed, the next phase in the estimation is "Quantity Takeoff". The option "Takeoff" is selected from the project menu. This dialog box has all the inquiries listed; as the current project inquiry is selected, details of the project are displayed. Estimate for Labour, Material, Equipment and/or Sub can be selected and worked upon that particular component of the inquiry.

Due to the surge in the number of fast-track projects involving design and construction, changes within projects are occurring more frequently. New versions of design drawings are received almost daily to update the existing set of drawings. There is an option in the application to identify the version of the estimate for each component of the inquiry. When a user selects any component of the inquiry, user is shown the latest version of it. As a new

version is identified, the old version is locked and all the old files are automatically copied into the latest version for updating. This feature of the application satisfies the need for an effective solution to deal with frequently occurring design changes.

After the latest version is selected for quantity takeoff, "pre-estimation details" dialog box is prompted. This displays the list of predefined Job numbers and the corresponding descriptions. The applicable jobs are selected from the list and drag-drop to the current estimate. Once the current job list is ready, the final estimate dialog box shows the quantity takeoff for the selected case study.

The final takeoff dialog box contains a list of the jobs selected from the previous dialog box for this version of the estimate. As a particular job number from the displayed list is selected, details regarding the job are shown on the right-hand side of the list as shown in the Figure 50. Since the job selected in this case example involves pipe, the details include ISO number, Line number, Specification, Pipe type, and Diameter. The spark and hydro details are automatically calculated based on the company's policies and standards. The "Factor" column allows for the application of different productivity factors for each of the takeoff scopes. Applying factors is one of the most difficult components in the bidding process and often lands most contractors in trouble. The real-time information drawn from the cost/schedule model for existing projects could assist the estimator in fine-tuning the productivity factors for each cost code in the bid. This is especially important in the current scenario, which witnesses declining productivity of relevant workforces.

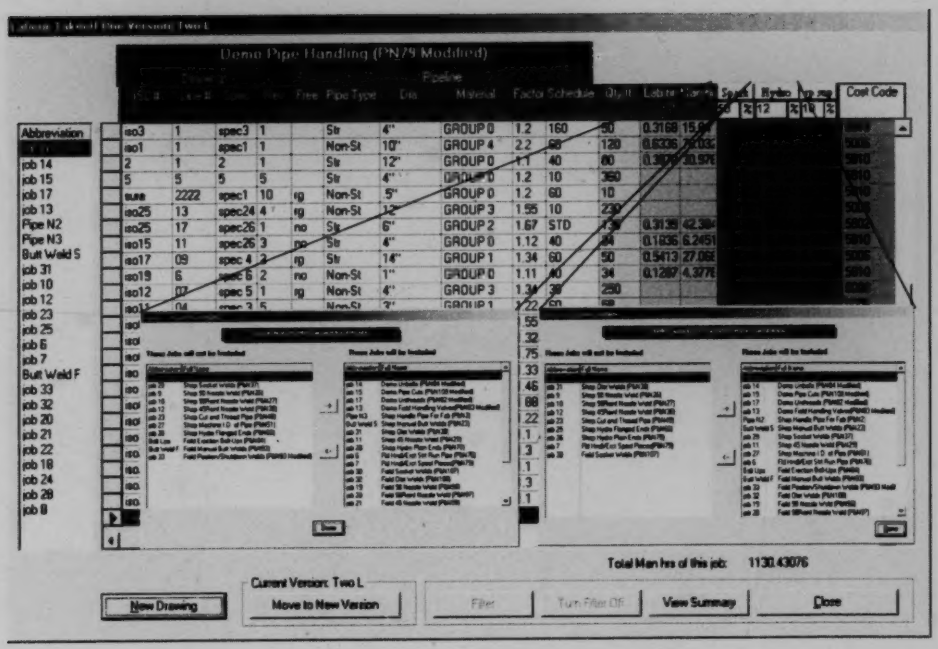


Figure 50: Automated Estimation Results in Information Management System

Based on the stated data, the cost code is automatically generated. Once details about the project are entered in the takeoff window, total man-hours required to complete a job and the bid summary is automatically generated. The whole process is efficient and allows the user to interact with the company database to ensure that the data is correct and complete. The application allows for additional takeoff items over and above those stored in the database, which provides the estimator with further flexibility. The bid summery is generated automatically based on the data entered and is stored in the database of projects for future bids. This serves the dual purpose of keeping track of the client's (owner's) jobs performed in the past and streamlines the reusability of the estimate in the detailed estimate process in a case where the bid is successful and the job is awarded to the contractor.

Table 3: Pipe Categories

Group 1	ASTM A335-P1 (.50% Moly)	**Group 4**	Stainless Steels Types 304, 310, 316(Including "L" &"H" Grades)
	ASTM A335-P2 (.5-.7% Chr.)		
	ASTM A335-P12 (.85-1.1% Chr.)		
	ASTM A335-P11(1.05-1.45% Chr.)		
	ASTM A335-P3 (1.5-2 % Chr.)	**Group 5**	Copper, Brass, Everdur
Group 2	ASTM A335-P3b (1.75-2.25% Chr.)	**Group 6**	ASTM A 333 – GR - 1
	ASTM A335-P22 (2.02-2.50% Chr.)		ASTM A 333 – GR4
	ASTM A335-P21 (2.75-3.25% Chr.)		ASTM A 333 – GR 9
	ASTM A335-P5,b,c(4–6% Chr.)	**Group 7**	Hastelloy, Titanium, 99% Ni
Group 3	ASTM A335-P7(6–8% Chr.)	**Group 8**	Stainless: 321&347, Cu-Ni
	ASTM A335-P9 (8–10% Chr.)		Monel, Inconel, Incoloy, Alloy 20
	Ferritic Chromes(10–15% Chr.)	**Group 9**	Aluminum
	ASTM Gr. 3 (3.5% Nickel)		

Typical reports and processes that can be generated from this data are line-wise quantity take-offs for piping systems, estimations, procurement reports and procurement management systems, log file generations, inquiry detail setups, vendor screening and selections, man-hour details, cost codes setups, pipe properties setups, checklists etc. Piping system consists of various components with different material compositions. Pipes are grouped and stored into nine different categories for calculating man-hours as shown in the Table 3. These material categories are used in the information management systems to organize and process the imported data from the 3D-CAD information system.

The information management system automates the pre-bidding process and minimizes human error and other communication-related limitations in the estimation process. The data files are electronically transferred from one user to another and thus eliminate a possible communication gap that would delay processing. This research also contributes to the automation of the pre-bidding process in order to increase bid-process efficiency and to minimize possible human errors and the risks associated with this process.

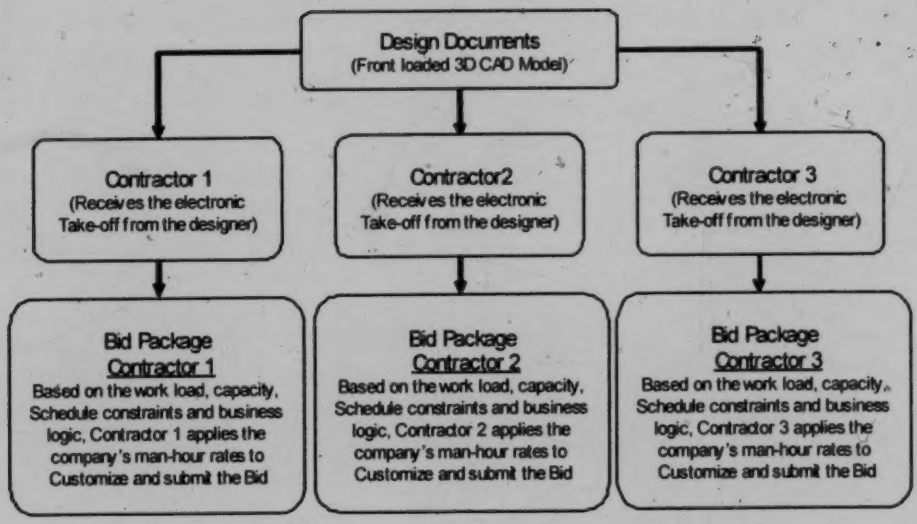

Design Documents
(Front loaded 3D CAD Model)
Contractor 1
(Receives the electronic Take-off from the designer)
Contractor2
(Receives the electronic Take-off from the designer)
Contractor 3
(Receives the electronic Take-off from the designer)
Bid Package
Contractor 1
Based on the work load, capacity, Schedule constraints and business logic, Contractor 1 applies the company's man-hour rates to Customize and submit the Bid
Bid Package
Contractor 2
Based on the work load, capacity, Schedule constraints and business logic, Contractor 2 applies the company's man-hour rates to Customize and submit the Bid
Bid Package
Contractor 3
Based on the work load, capacity, Schedule constraints and business logic, Contractor 3 applies the company's man-hour rates to Customize and submit the Bid

Figure 51: The Data Flow in the Bidding Stage

Figure 51 shows the modified data flow in the pre-bidding stage to minimize the communication gap between disciplines. Designer prepares the front loaded design documents using available project documents and information. The design documents are electronically transferred to various contractors for bidding. Each of the contractors receives the same version of electronic drawings with front loaded data about the project. Contractors have to apply company's man-hour rates and other business logic to modify the bid package and submit. This system minimizes data redundancy and improves collaboration between disciplines in the pre-bidding process. A typical estimation process in any industry contains quantity take-off process along with pricing, coordination, basis of estimation etc. The proposed system automates the quantity take-off process hence minimizing the man-hour requirement for the same. Figure 52 shows a typical estimation man-hour break-up for a project. As the figure shows almost 50% of the man-hour is consumed in the take-off process which constitutes a major chunk of the estimation

man-hours. This process is significant considering the fact that estimation process itself constitutes 15-25% of the project budget.

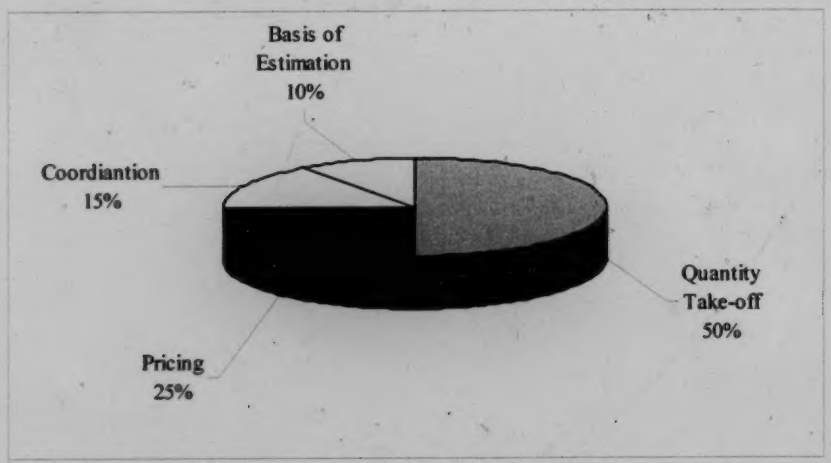


Figure 52: Typical Estimation Man-Hours Break-up

The advantages and limitations of the 3D-CAD information system are categorized as show below:

Advantages

1. Easily customizable to suit company specific needs.
2. Robust architecture and use of Universal Data Exchange (UDE) file makes this system compatible with other similar systems.
3. Saves man-hours to prepare ISO's, shop drawings, field drawings and quantity take-off.
4. Minimizes human error and expedites pre-bidding process.
5. Minimizes data redundancy by using central data storage system.
6. Cost effective and less complicated compared to CIM and other systems.

Further to this, generally a contractor wins 1 bid out of 15 bids. The lost bid requires man-hours to do quantity take-off and bid preparation. This system reduces time and effort spent on the bids. Customized spreadsheet software and information management system uses manual data entry for the quantity take-off, which can be eliminated by using this 3D-CAD information system.

Limitations

1. The proposed system is compatible only with the information management system.
2. Data structure has to be changed to make it compatible with other systems.
3. High dependence on the quality of 3D drawings.
4. Does not have intelligence or decision making ability.
5. Accuracy of quantity take-off is dependent on quality of data used to generate 3D drawings.
6. Knowledge of Data Transformation System (DTS) is necessary for modifications / maintenance.

CHAPTER 5: SUMMARY AND CONCLUDING REMARKS

5.1 Conclusion

This thesis describes a methodology to improve information collaboration between the various disciplines by providing a tool for sharing project information. The methodology minimizes redundant activities performed during the design and construction phases of the project by automating the quantity take-off process using 3D-CAD model. The proposed methodology has been incorporated into a computer system that integrates the 3D-CAD model with the information management system using a central database. The database is designed using the Entity Relationship (ER) diagram and implemented using Microsoft SQL 2000 DBMS. Data Transformation Service (DTS) is used to manipulate and export the data to the information management system. This research has focused on large-scale industrial projects and intended users of this system are the project managers, designers, planners, estimators and other decision maker. The proposed system has a repository, which incorporates information from design, construction and commissioning phases of the project and later utilizes it for future projects. This repository can also be used as a source of information for maintenance and operation.

5.2 Research Contributions

The contributions of this research can be summarized as follows:

- The proposed system integrates 3D-CAD model with information management system to automate the manual quantity take-off process.
- The proposed methodology improves the information collaboration between various disciplines by providing a tool for project information sharing.

- The system permits integration between applications through a central database for efficient processing of the project data.
- The system uses an object oriented models for cross platform communication between 3D model and the information management system.
- The system paves the way for incorporating lean thinking to minimize redundant activities.

In addition, the developed methodology assists decision makers, designers, estimators, and planners in the bid preparation process. The proposed system functions as an effective information repository for the lessons learned from each project and repository can be utilized in new project. This facilitates information management for a company and minimizes errors. The storage of project data in a central database allows all the project participants to access historic and current data in a central location, ensuring consistency, integrity, and accuracy.

5.3 Recommendations for future research

This research proposes a system that automates the quantity take-off and information transfer between the design, construction and estimating disciplines. Further expansion of the proposed model includes modification of the methodology to provide additional functionality and expanded integration with the central information management system. The following is a list of recommendations for future developments:

1. Develop a methodology to input the schedule data at the design phase of the project and integrate this new system with the central information management system. This expansion will add to the existing system architecture and has the potential to solve many data communication problems.

2. Incorporate 4D scheduling techniques that permit the visualization of the actual progress compared to the planned progress which enables management to take corrective measures. This 4D scheduling module can be integrated with the existing central information system to enhance its functionality.
3. Build a construction module to collect, analyze, and update actual progress data from site and compare it with the planned progress data. Also, implementation of a 3D visualization system to show visual results of the progress.
4. Enhance the existing central database to accommodate the expansion and addition of newer modules to the system. Modified database can be used to store the project's actual data and other additional data to be presented in the information management system.

CHAPTER 6: REFERENCE

Aouad, G., Sun, M., Bakis, N., Birchall, S., Swan, W., (2000). "An Integrated Web-Based Virtual Model to Support Housing Projects". *Proceeding of the 28th IAHS World Congress on Housing, Challenges for the 21st Centrual* , Abu Dhabi: 433-444

Bell, L. C., Elzarka, H. M. (1992). "Expert Systems Application and Tutorial". *Source Document No. 75*, Construction Industry Institute, Austin, Tex.

Choi, K. C., Ibbs, C. W. (1989). "Cost Effectiveness of Computerization in Design and Construction". *CII Source Document 50*, University of Texas, Austin, Texas August

Chaffin, M., Knight, B., and Robinson, T. (2000). "Professional SQL Server 2000 DTS". *Wrox Press*, ISBN: 0764543687

Elmasri, R., and Navathe, S. B. (1994). "Fundamentals of Database Systems". *Addison-Wesley Pub*. Menlo Park, California, ISBN: 0805317481

Froese, T., Waugh, L., and Pouria, A. (2001). "Project Management in The Year 2020", *Proceedings of 2001 Conference of the Canadian Society for Civil Engineers*, Victoria, BC., May 30-Jun 2.

Jrade, A. (2000). "A Conceptual Cost Engineering Computer System for Building Projects". *M. A. Sc. Thesis*, Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Canada

Jrade, S. Alkass (2003). "Computer Integrated Virtual 3D Model for Conceptual Cost Estimate". *5th Construction Specialty Conference of the Canadian Society for Civil Engineering*, Moncton, Nouveau-Brunswick, Canada June 4-7, 2003

Kangari, R., Yoshida, T. (1909). "Automation in Construction". *Robotics Int. J.*, 6, 327-335

Kunigahalli, R. (1997). "3D Modelling for Computer-Integrated Construction of RC Structures". *Journal of Computing in Civil Engineering*, 2:92-101

Levitt, R. (1990). "Merging, Artificial Intelligence with CAD: Intelligent, Model-based Enginnering". Twenty-eight Henry M. Shaw Lect. in Civil Engineering, North Carolina State University, Raleigh, N.C.

Morad, A., Beliveau, Y.J. (1991). "Knowledge-based Planning System". *Journal of Construction and Management*, ASCE, 117(1)-12

Mousa Tabatabai-Gargari, Hazem M. Elzarka (1998). "Integrated CAD/KBS Approach for Automating Preconstruction Activities". *Journal of Computing in civil engineering*, ASCE, Vol. 124, No.4, July/August, 1998. ISSN 0733-9364/98/0004-0257-0262. Paper No17394

Nayyar, M.L. (2002). "Piping Handbook", McGraw-Hill, New York, c2000, ISBN: 0070471061

Parker, D.E., Dell'Isola, A. (1991). *Project Budgeting for Buildings*. Van Nostrand and Reinhold, New York, N.Y.

Reinschmidt, K. F., Finn, G. A. (1990). "Integration of Expert Systems, Databases, and Computer-aided Design". *Intelligent design and manufacturing*, John Wiley & Sons, Inc., New York, N. Y., 1-21

Statistics Canada, "The Daily", catalogue number 11-001-XIE, Apr 30, 2003

Tabatabai-Cargari, M. (1993). "Behavior Modification of Space Trusses", *PhD thesis, Center for Building Studies*, Concordia University, Montreal, Quebec, Canada

Teicholz, P., Fischer, M. (1994). "Strategy for Computer Integrated Construction Technology". *Journal of Construction Engineering and Management*, ASCE, 120:117-131

Tucker, R. L., Scarlett, B. R. (1986). "Evaluation of Design Effectiveness". *CII Source Document 16*, University of Texas, Austin, Texas July

Vaha et al. (1997). "Use of 3-D Product Models in Construction Process Automation". *Automation in Construction*, 2:69-76

Vaugn, F. (1996). "3D & 4D Modeling on Commercial Design-Build Projects". *Computing in Civil Engineering*, Proceeding of 3rd Congress Held in Conjunction with A/E/C Systems: 390-396

Wael El-Ghandour, Aubrey Vanderstar, Mohamed Al-Hussein, Simaan AbouRizk (2003). "An Automated System for Cost Estimating and Cost/Schedule Control for Industrial Construction Projects". *5th Construction Specialty Conference of the Canadian Society for Civil Engineering*, Moncton, Nouveau-Brunswick, Canada June 4-7, 2003

Whyte, J., Bouchlaghem, D., Thorpe, T. (1998). *"The Promise and Problems of Implementing Virtual Reality in Construction Practice"*. CIB 1998

Williams, T. P., Kangari, R. (1988). "An Example of Knowledge-based System for Planning a Construction Operation". *Int. J. Microcomputers in Civil Engineering*, 3(4), 345-353

Yamazaki, Y. (1991). "Integrated Design and Construction Planning by Knowledge-based Systems". *Proc., Construction Congress' 9*1, ASCE, April 13-16, 400-405

Yasuyoshi Miyatake, Roozbeh Kangari (1993). "Experiencing Computer Integrated Construction". *Journal of Construction Engineering and Management*, ASCE, Vol. 119, No. 2, June, 1993. ISSN 0733-9364/93/0002-0307, Paper No. 3898